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THESIS

ENERGY EFFICIENT WASTE HEAT RECOVERY FROM AN ENGINE EXHAUST SYSTEM

by

Aaron R. VanDenBerg

December 2016

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The research for this thesis also included a comparative analysis of three different waste heat recovery cycles to determine which cycle would function best on US Navy ships. The analysis compared the three cycles while assuming the exhaust flow is from an LM2500 gas turbine engine, similar to the engines currently powering US Navy ships.

The design of a new heat exchanger with the intent of minimizing any gains to back-pressure as well as the analysis of the various waste heat recovery cycles allowed this thesis to make recommendations to the Navy about which cycle should be used on US Navy ships through the new heat exchanger.

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ENERGY EFFICIENT WASTE HEAT RECOVERY FROM AN ENGINE EXHAUST SYSTEM

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LIST OF ACRONYMS AND ABBREVIATIONS

2-D	two dimensional
3-D	three dimensional
CFD	computational fluid dynamics
CFM	cubic feet per minute
CO_2	carbon dioxide
CRS	Congressional Research Service
DOD	Department of Defense
DOE	Department of Energy
DON	Department of the Navy
ESTEP	Energy Systems Technology Evaluation Program
GE	General Electric
HP	high pressure
LM2500	gas turbine engine used in Navy ships
LT	Lieutenant
N-S	Navier-Stokes
NASA	National Aeronautics and Space Administration
NPS	Naval Postgraduate School
PDE	Partial Differential Equation
SECNAV	Secretary of the Navy
T-S	Temperature-Entropy
US	United States
USMC	United States Marine Corps
USN	United States Navy
WHR	waste heat recovery

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NOMENCLATURE

Symbols	Equation	Description	Units
C_p		Specific heat capacity	kJ/kg*K
η	$\frac{Heat_{in,\mathrm{real}}}{Heat_{in,ideal}}$	Thermal efficiency	[-]
h		Specific enthalpy	kJ/kg
k		Thermal conductivity	W/m*k
μ		Dynamic viscosity	Pa*s
ν		Kinematic viscosity	m^2/s
P		Pressure	Pa
ρ		Density	kg/m^3
s		Specific Entropy	kJ/kg*K
T		Temperature	K
u		X-coordinate velocity	m/s
u*	$\sqrt{\frac{\tau_w}{\rho}}$	Friction velocity	m/s
v		Y-coordinate velocity	m/s
w		Z-coordinate velocity	m/s
Y+	$\frac{yu^*}{\nu}$	Non-dimensional distance	[-]
y		Distance from tube wall	m

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I. INTRODUCTION

A. US NAVY ENERGY GOALS

The United States (US) Department of Defense (DOD) is the largest consumer of energy in the country [1]. In 2012, the Secretary of the Navy (SECNAV) published the "Strategy for Renewable Energy" in which he laid out his goals for the Department of the Navy (DON), which includes the United States (US) Navy (USN) and the United States Marine Corps (USMC), to work toward energy independence. He stated that, by the year 2020, the DON should produce at least 50% of its energy consumption by renewable methods [2]. For ships, a 50% reduction is a more difficult goal to accomplish than for shore installations. Ships do not have the space that solar panels or a wind turbine would require to produce enough power to be useable. Also, today's Navy ships are built to be stealthy and have a small radar cross section; adding a turbine or solar panels would greatly reduce the stealth of the ship and greatly increase the radar cross section, making them much easier targets.

Since solar panels and wind turbines will not work for ships; the energy savings must come from making the existing power generation processes more efficient. USN destroyers and cruisers, for example, have four LM2500 gas turbines produced by General Electric (GE) in each ship which are used for propulsion. Each LM2500 produces 24,050kW (32,251SHp) with a fuel flow rate of 227g/kW-hr (0.323lb/SHp-hr) [3]. So, if all four of the gas turbines are operating at full power, the ship will be burning fuel at an approximate rate of 5,459.4kg/hr (10,417.1lb/hr) [3]. Unfortunately, most of the heat that this fuel produces in the engine is lost out the exhaust stack. The exhaust from the engine is typically around 566°C (1051°F) and flows at a rate of 70.5kg/sec (155lb/sec) [3]. Due to this lost heat, the efficiency of the LM2500 is only 36% [3]. This high temperature and high flow rate exhaust equates to lots of lost energy from the fuel and does not include the amount of fuel used for electrical generation for the ship.

Political leadership has noticed the DON's high use of fuel. In 2012, the Congressional Research Service (CRS) published a report about how much fuel and energy the Department of Defense (DOD) uses and what that costs the taxpayers. According to the report, the DOD used more than 18.603 billion liters (4.914 billion gallons) of fuel [4].

The DOD is divided into three main branches of the military. Figure 1 shows the breakdown of how much fuel each different branch of the DOD uses. The DON, including the USMC, uses approximately 28% of the total fuel used by the DOD. USN ships use about 43% of that 28%, which means nearly 2.240 billion liters (592 million gallons) of fuel was burned in 2011 [4]. This large amount of fuel burned solely by the ships are the reason that the DON is interested in coming up with ways to reduce the fuel burned and be able to extract as much energy out of the fuel as possible.

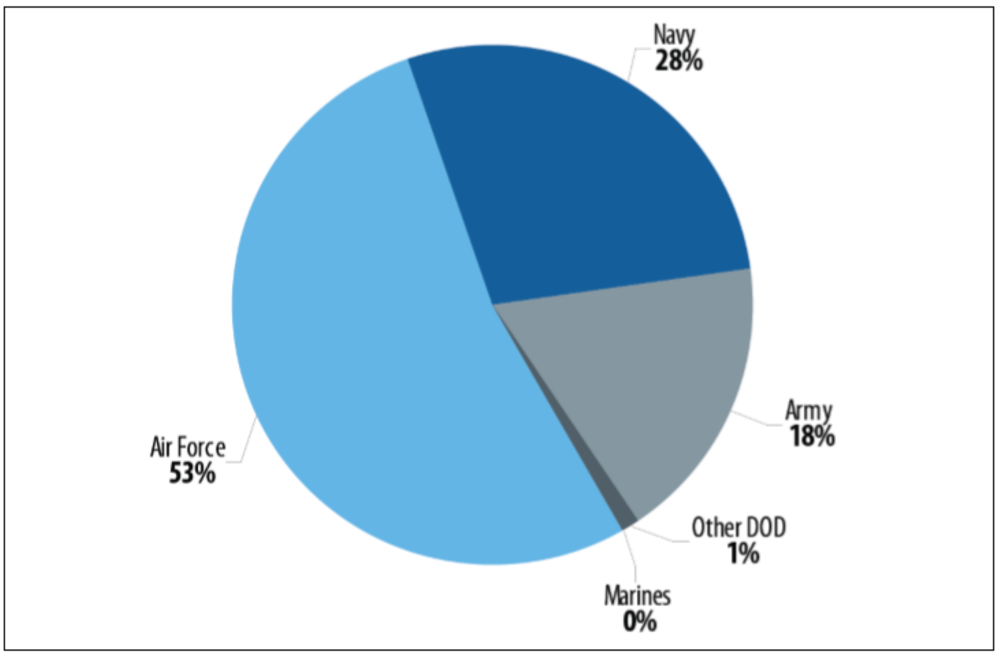

Figure 1. DOD Fuel Consumption by Military Branch. Source: [4].

Since the DON needs to reduce fuel usage, they are especially interested in finding ways to extract waste heat from the exhaust of engines. The DON has teamed up with the Naval Postgraduate School (NPS) to create what is known as the Energy Systems Technology Evaluation Program (ESTEP). The ESTEP program provides funding for NPS students to research new and innovative ways for the Navy to become more energy efficient [5].

The research that this thesis presents covers the areas of pressure drop mitigation and heat exchanger designs, as shown in Figure 2. Pressure drop mitigation is an active area of research aimed at reducing the amount of back-pressure the exhaust duct and heat exchanger place on the engine while operating. Higher back-pressure leads to the engine being less efficient and burning more fuel to achieve the same power output. Heat exchanger design is aimed at designing an effective and compact heat exchanger that will have minimal impact on the exhaust back-pressure.

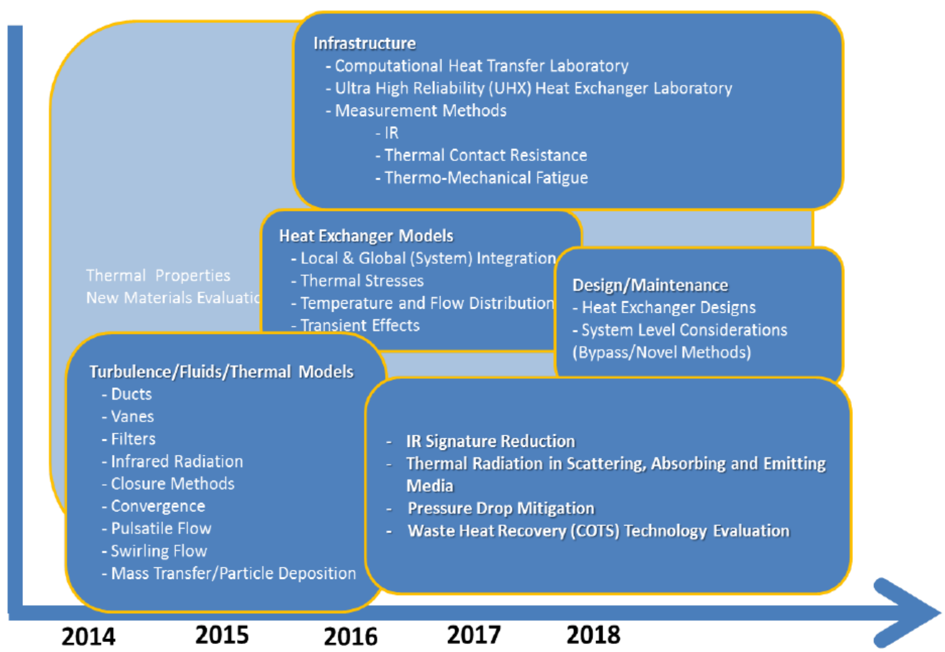

Figure 2. USN and NPS ESTEP Proposed Timeline. Source: [5].

B. BACKGROUND: WASTE HEAT RECOVERY DEVICES

Ships mainly extract heat and energy from exhaust gases by using a waste heat boiler located in the actual exhaust duct. The exhaust gases flow through these shell and tube heat exchangers, which transfer heat to boil the water inside the tubes. This method of heat extraction has one main downside. The exhaust gases flowing around the water tubes increases the back-pressure of the exhaust gas on the engine, causing the engine to work harder and burn more fuel to achieve the same power output.

1. Waste Heat Recovery Devices in Merchant Ships

Almost all commercial cargo ships around the world today contain waste heat recovery (WHR) devices built in to the exhaust ducting from the main engine. These boilers are used to create steam for the use of heating the fuel tanks and for pre-heating the fuel prior to and after purification before it gets injected into the engine. This steam heating ensures that the fuel is at the proper viscosity for purification and combustion.

Using the steam heated by the exhaust gases prevents the ship from having to produce electricity for heating all of the fuel tanks and pre-heaters, which saves fuel and energy costs for the operation of the ship. The types of boilers used in this process are specially built to have water flowing around thousands of tubes through which flows the engine’s exhaust gas. These boilers are also meant to be used by an engine that is constantly at or near maximum power, which allows for the temperatures of the metal and the water to be at equilibrium for as long as possible. Rapid changes in engine output would cause an uneven heating of the water and metal heat exchanger, leading to damage or possible failure of the boiler.

Since the merchant vessels operate at near constant speeds, the waste heat boilers are a useful money-saving technique for the shipping companies. The energy saved by extracting the heat saves fuel money as well as lowers the amount of pollution that the ships generate while operating.

2. History of Waste Heat Recovery Units on USN Ships

The styles of boilers that require the engine to be kept at a near constant level of power are not as useful to the Navy. The military ships usually never stay at a constant power, and the main engines have to be able to react to engine orders rapidly and come up to power quickly. These changes in speed would cause the waste heat boiler’s production of steam to fluctuate which would require an electrical backup system for any service that the steam is used.

The USN's CG-47 Ticonderoga class cruisers were all constructed with waste heat boilers installed in the exhaust ducts in order to recover some of the lost heat. The steam from the boilers was distributed throughout the ship to provide heating to systems like the distilling unit, washers, dryers, dishwashers and fuel oil heaters for example [6]. These boilers were installed in order to attempt to recapture some of the heat from the LM2500 gas turbine main engines to try to make the ship class more energy efficient.

The steam systems installed in the cruisers were far from ideal. Finally, the DON determined that the WHR units cost too much in repairs and maintenance. Removal of the boilers and steam piping from the ships became the most economical option for the DON. Figure 3 shows one of the boilers from the cruiser Hue City being removed through a hole cut into the hull of the ship.

Figure 3. Waste Heat Boiler Being Removed from USS Hue City (CG 66). Source: [7].

The use of "wet steam" in these systems was one of the main causes of the high occurrence of needed repairs [8]. This style of steam system creates a very corrosion-intensive environment and costs the DON time and money in repairs to the systems and piping that runs all over the ship. The steam system and piping have been replaced by all electric components on the cruisers. Since the DON finished building the Ticonderoga class cruisers, no USN ships have been fitted with a WHR unit.

C. LITERATURE REVIEW

Most industries that have to handle a hot stream of air vented to the atmosphere employ WHR devices. Rather than wasting the heat, companies study and some innovate ways to re-use that heat and transform it into electricity as efficiently as possible.

1. Echogen EPS100 Heat Recovery System

For example, Echogen came up with a new way to extract the heat from exhaust ducts and turn it into electricity. Their solution uses carbon dioxide (CO_2) as the working fluid of the heat recovery unit instead of water, allowing greater reliability and a more compact system [9]. They also claim that this unit will produce up to 8.0MW of power [9]. While likely suitable for shore-based power plants, Echogen systems could be used on naval ships.

Since Echogen is manufacturing and selling these WHR devices, they publish as little information about the operation of their system as possible. However, from the schematic in Figure 4, a very basic analysis of the system can be accomplished. First, since the system uses a pump instead of a compressor, this cycle more than likely operates using a Rankine cycle instead of a Brayton cycle. For the CO_2 inside the system to be a liquid and boil inside the heat exchanger, the system would require a very high pressure heat exchanger. This high pressure heat exchanger would increase the complexity of the manufacturing and design of the system. The schematic also shows that the WHR heat exchanger fully covers the area of the exhaust duct. While this schematic may not be an accurate depiction of the actual machinery, the size of the heat exchanger likely at least minimally affects the engine due to the increase in back-pressure.

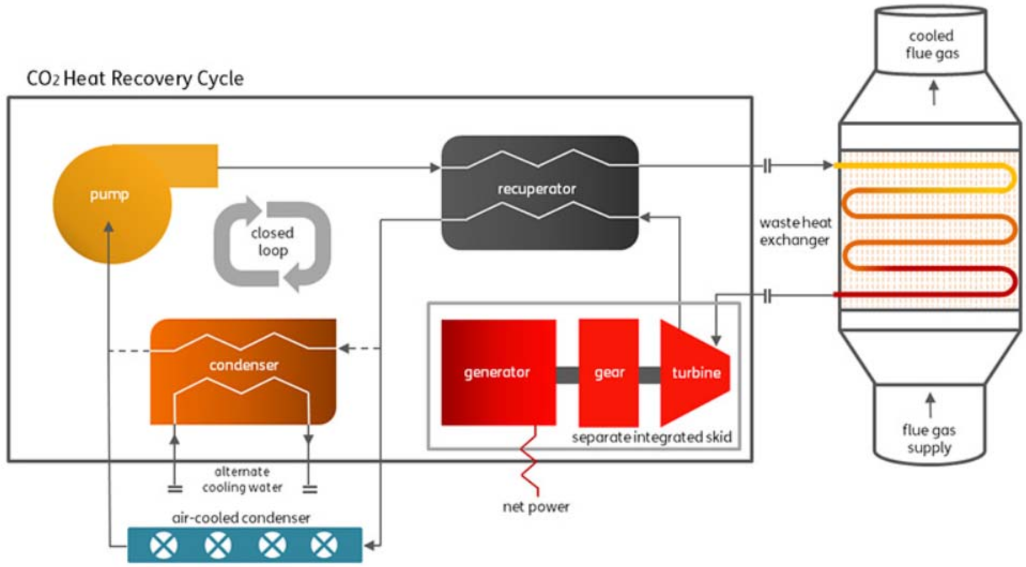

Figure 4. Echogen EPS100 Cycle Diagram. Source: [10].

2. Alphabet Energy Solution

Alphabet Energy has also designed a new and unique solution for WHR. They have created what they call the PowerModule-γ™ [11]. This new WHR design is a heat exchange and power generator all in one small device designed for use on exhaust flows as small as an automobile exhaust.

The unit fully assembled and ready to install into an exhaust gas flow is shown in Figure 5. The unit can handle up to 6.25m^3/min (221CFM) of exhaust gas flow and convert the energy to electricity. While this is a smaller unit, the output power is quoted to be around 417W with exhaust temperature similar to the gas turbine used in this thesis. This unit does create an increase in back-pressure to the engine of 930Pa (0.135psi) [11]. When multiple units would be aligned in parallel, this back-pressure value could potentially increase which would cause the engine to lose efficiency.

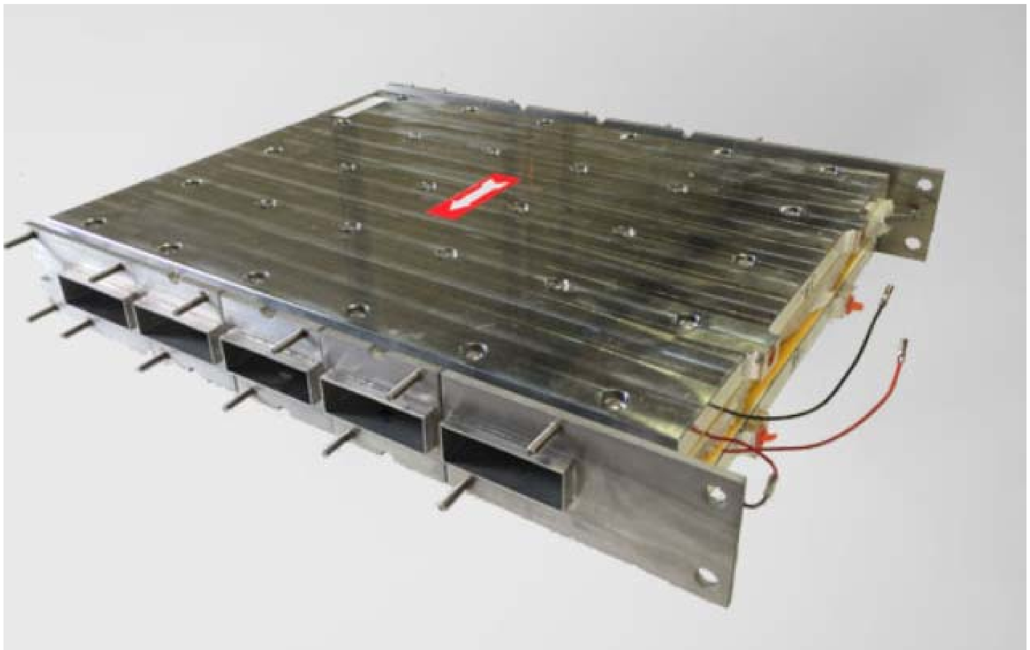

Figure 5. The PowerModule-γ^{TM} Produced by Alphabet Energy [11].

The benefit to having this unit installed comes from the power generation that comes directly out of the unit, so this system remains very compact and easy to use in systems that do not have much excess space around them. Ships do not have excess space for a large WHR system, so making use of a compact solution such as the PowerModule-γ^{TM} would be an effective solution.

3. Past NPS Thesis Work

NPS students and faculty have been researching new methods for WHR for several years; several theses have suggested new and innovative solutions to the problems of recovering waste heat from exhaust.

a. Thesis Work Done by Mark A. Beale

LT Mark Beale's work concerned where to place and how many turning vanes were necessary to assist the flow when going around a 90° bend. He ran many CFD models to determine the most effective placement of a turning vane. He started with a single turning vane located near the bottom side of the bend and continued to vary the distance from the apex of the bend to the turning vane in order to optimize the flow path and reduce the back-pressure of the flow on the engine [12].

His results showed that either a single turning vane in the center of the duct or three equally spaced turning vanes created a 50–60% reduction in the back-pressure of the flow going around the bend [12]. This drastic reduction in pressure showed a relatively easy way to lower the back-pressure of a flow through a duct with multiple sharp bends [12].

These results proved the effectiveness of optimally placing turning vanes in exhaust flows nears bends or corners. This turning vane idea helped to shape the work of this thesis by considering if heat can be extracted from the turning vanes in the exhaust flow.

b. Thesis Word Done by Ryan S. Bohning

LT Ryan Bohning's work was more geared toward being able to extract the heat from the exhaust duct without actually placing any equipment in the duct. This would avoid any increase in back-pressure that would come from placing intrusive equipment in the exhaust stream itself. In his modelling, he used flat plates designed to absorb heat and transmit it to power production equipment elsewhere. His main focus was on determining the best place to put the heat absorbing plates in order to direct the maximum amount of heat out of the exhaust flow [13].

Bohning's results showed that the best area to place these heat absorbing pads was on the wall just after a 90° bend where a large recirculation zone was formed [13]. This zone allowed the flow to slow down and thus transfer more heat to the absorbing pads than the other walls of the exhaust duct [13].

Being able to unobtrusively extract the heat from the exhaust flow was a new idea and proved to be a useful concept. If the exhaust duct remains unchanged, the back-pressure on the engine will not increase while the heat is being extracted.

D. GOVERNING EQUATIONS

Prior to utilizing a Computational Fluid Dynamics (CFD) solver to perform a complex analysis of a fluid flow, the basic equations that govern the flow should be known and understood. The main point of the governing equations that should be known and understood is that the equations cannot be fully solved for the fluid problem. The CFD solver uses turbulence models that approximate the flow and simplify the equations in order to achieve an approximate solution to the problem. The research for this thesis involved design by analysis of heat exchange in a gas turbine exhaust duct. This requires the CFD model to account for turbulent flow and heat transfer within the exhaust duct. This is critical since both of these flow characteristics have large impacts on the final solution of the model.

1. The Continuity Equation

The continuity equation is governed by the law of the conservation of mass. The equation is derived from a unit cube of fluid, with 3-D flow entering and exiting the cube. The equation is the balance of the fluid entering and exiting the cube such that all of the mass is conserved (i.e., no mass is created or destroyed).

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

In this study, the model was always solved using a steady state analysis, which simplifies the problem by allowing all time based derivatives to go to zero. This eliminates the first term of Equation 1.

2. The Conservation of Momentum Equations (Navier-Stokes)

The conservation of momentum equations are derived from Newton's Second Law that force is equal to mass multiplied by acceleration [14]. This law is applied to a fluid particle and then expanded into 3-D partial differential equations (PDEs).

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=X-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \tag{2}$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=Y-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \tag{3}$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=Z-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \tag{4}$$

Equations 2–4 are the Navier-Stokes (N-S) equation in Cartesian coordinates.

3. The Viscous Energy Equation

The viscous energy equation is derived from an energy balance of a unit area of a fluid flow involving convective heat transfer. The general form of the equation contains terms for all of the energy transfer possible [15]

$$\begin{aligned}\left(\rho u\frac{\partial i}{\partial x}+\rho v\frac{\partial i}{\partial y}+\rho w\frac{\partial i}{\partial z}+\rho\frac{\partial i}{\partial t}\right)-\left[\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)-\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)-\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)\right]\\ -\left[\frac{\partial}{\partial x}\left(\sum_j\gamma_j\frac{\partial m_j}{\partial x}i_j\right)+\frac{\partial}{\partial y}\left(\sum_j\gamma_j\frac{\partial m_j}{\partial y}i_j\right)+\frac{\partial}{\partial z}\left(\sum_j\gamma_j\frac{\partial m_j}{\partial z}i_j\right)\right]\\ -\mu\phi-\left(u\frac{\partial P}{\partial x}+v\frac{\partial P}{\partial y}+w\frac{\partial P}{\partial z}+\frac{\partial P}{\partial t}\right)=S,\end{aligned} \tag{5}$$

where

$$\begin{aligned}\phi=2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]-\frac{2}{3}\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right]^2\\ +\left[\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right]\end{aligned} \tag{6}$$

and i is the enthalpy, and for a perfect gas is equal to C_pT.

Equation 5 when combined with Equation 6 allows for the full solution to any convective heat transfer problem. However, like the N-S equations, the viscous energy equation can only be fully solved for a very select few problems. This equation when combined with the continuity and N-S equations allow a CFD solver to model a fluid flow with heat transfer occurring and return an accurate estimate of the solution.

E. OBJECTIVES AND GOALS

This thesis intends to come up with a new design for an exhaust gas WHR heat exchanger that is installed in the exhaust gas flow and also does not increase the back-pressure on the engine itself. This involves modifying the existing exhaust duct by locally increasing its cross sectional area and also laying out the heat exchange tubes in such a way as to not impede the exhaust gas flow over the tubes.

The present research is intended to build upon the theses of LT Beale and LT Bohning and, in a way, combine their results in the creation of a new style of heat exchanger. Instead of using a heat absorbing plate on the outside of the exhaust duct, the intent is to look into the idea of using the pipes of the heat exchanger in the shape of a turning vane in a corner to extract the heat and turn the flow at the same time.

The heat exchanger and full WHR system design will also be based on a CO_2 Brayton cycle instead of the more commonly used Rankine cycles, like the Echogen EPS100 and Alphabet Energy PowerModule-γ^{TM} were designed to use. The goal of using Brayton cycle is minimizing heat lost through a condenser and thus maximizing the power that can be extracted from the exhaust gases. This will involve a thorough analysis comparing the two cycles in order to determine if the Brayton cycle can indeed be a more efficient cycle to use for WHR.

This new heat exchanger design will then be built and tested on one of the exhaust gas ducts of an Allison 250 gas turbine engine currently in the main propulsion laboratory at NPS. This will allow for actual data runs and tests to obtain a proof of concept for the design and operation of the heat exchanger.

The radical new design of a heat exchanger being used as a turning vane would satisfy the ESTEP program goals of new heat exchange design and pressure drop mitigation shown in Figure 2. The idea of using a Brayton cycle instead of a Rankine cycle should in theory allow the heat exchanger to be more flexible to load changes based on the speed of the engine. This would result in a heat exchanger design that will work on a USN ship and would also be more corrosion resistant than the current WHR devices that are being removed from the ships.

Chapter II of this thesis shows the complete analysis of the Allison 250 gas turbine engine as well as the construction of the SolidWorks models of the exhaust ducts that were used as the basis for the CFD models. This analysis allows for the CFD models to be validated against the parameters of the actual engine. Chapter III of this thesis presents the steps that were taken to create the CFD model and validate the ANSYS model with the parameters of the engine that were solved for in Chapter II. Chapter III also lays out the iterations taken to finalize the design of the heat exchanger for the bend in the exhaust duct. Chapter IV analyzes the operation of the RankineCycler™, which is a Rankine cycle classroom demonstration tool. This analysis provides a comparison between a Rankine cycle and the Brayton cycle of the WHR unit when installed. Chapter V contains a comparative analysis between a Rankine, a transcritical, and a Brayton cycle for WHR using CO_2. Chapter VI lays out the results, conclusions, and recommendations of this thesis.

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II. WASTE HEAT RECOVERY FROM A TURBOSHAFT ENGINE

While a comprehensive literature review, as done in Chapter I, allows insight regarding companies are looking into for WHR devices, designing a new style of heat exchanger from scratch requires a different perspective. The innovative design process requires new ideas and also a certain amount of infrastructure to conduct testing on the new design. This thesis looks into new ways to extract heat specifically from a gas turbine exhaust, so an operational gas turbine engine was required.

A. THE ALLISON 250 TURBOSHAFT GAS TURBINE ENGINE

The Allison 250 gas turbine engine, now known as the Rolls Royce Model 250, remains a very widely used engine, first developed in 1961 by the Allison Company [16]. This particular engine was first produced for the U.S. Army in the late 1950s for the new helicopters that they were designing at the time [16].

This new engine had several key design aspects that separated it from the gas turbine engines of the day, most notably a change in the dual exhaust ports and their location. The engine featured dual ovular exhaust ducts which faced up at an angle of 45 degrees from the vertical. These angled exhaust ducts can be seen in Figure 6 covered with the yellow dust covers. Most gas turbine engines had the exhaust exiting the rear of bottom of the engine. The original design for the Allison 250 exhaust was to have them facing down, similar to other engines [16]. This design was changed due to the threat of starting a grass fire when they would land in a grassy area [16].

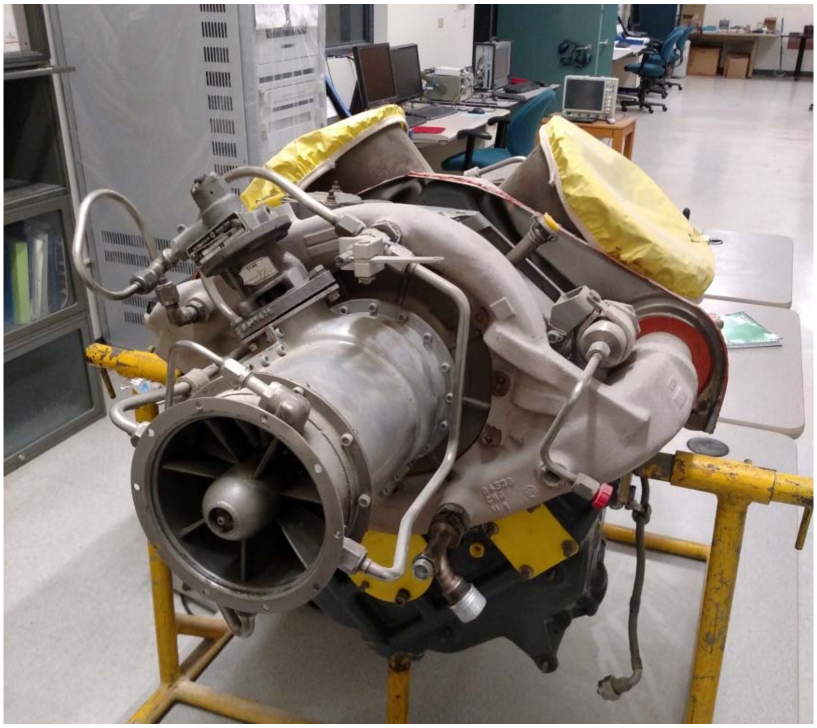

Figure 6. The Front of the Allison 250 Gas Turbine.

Another key difference in the Allison engine from most gas turbine engines concerns the air flow. The air flow through the Allison 250 engine does not follow the normal straight line. In this design, the combustion chamber was moved to the back of the engine where the high pressure and power turbines are normally placed. As shown in Figure 7, the combustion chamber can easily be seen, and this back-end placement facilitates easy removal and maintenance of that section of the engine. This new design criterion was requested by the U.S. Army since previous gas turbine combustion chambers required extensive maintenance.

Figure 7. The Back of the Allison 250 Gas Turbine Engine Showing the Combustion Chamber Placement.

The combination of air flow and dual exhaust ducts is ideal for this thesis's purposes. Figure 8 shows the actual air flow through the engine when operational. The air flow starts at the bell mouth of the engine and the runs through the multi-stage axial compressor. The engine diverts the high pressure air around the turbine and exhaust ducts and injects it into the back end of the combustion chamber. The hot combustion gases pass through the turbine and then exit through the twin ovular exhaust ports located in the middle of the engine.

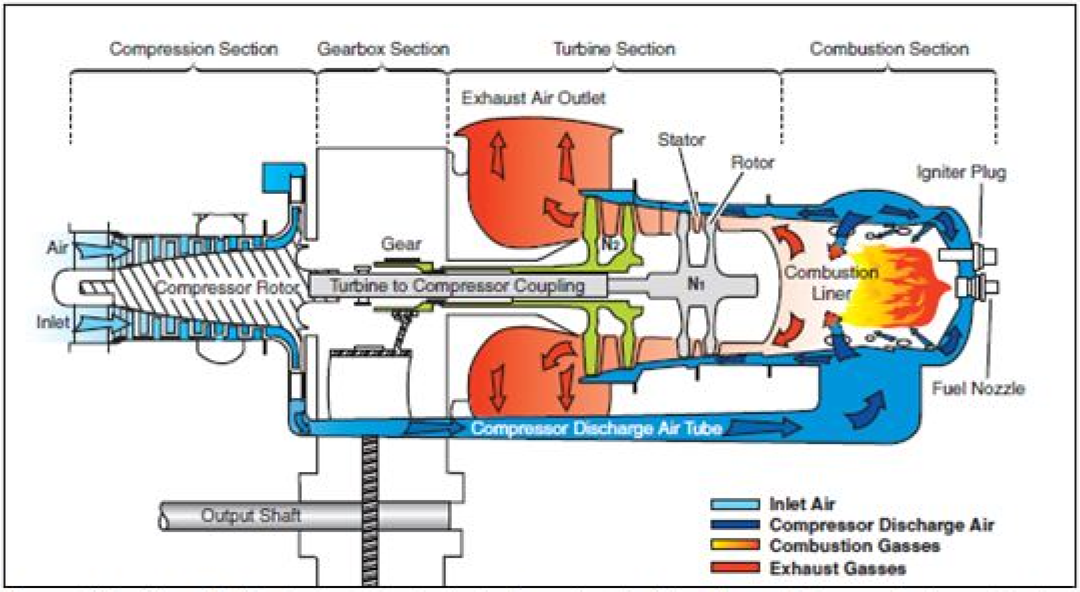

Figure 8. Schematic Diagram of Allison 250 Engine. Source: [17].

With the unique design and location of the exhaust ports, for this thesis's purposes, special exhaust ducting was manufactured for the test engine to allow for instrumentation and ease of removal. The dual exhaust ducts are ideal for doing any WHR research on this particular engine. By adding a WHR device to only one of the exhaust ducts, a comparative analysis can be performed. The exhaust gas back-pressure would be the main parameter to measure in the two ducts. The difference between the back-pressures would be an indicator of the effectiveness of the WHR design to mitigate an increase in back-pressure. Both of the exhaust ducts for the engine in the NPS test cell are identical and are easily removed either together or individually. The setup for the gas turbine test cell is shown in Figure 9.

Figure 9. NPS Gas Turbine Test Cell Exhaust Duct Setup.

The specialized setup allows the researcher to make any necessary modifications. The duct on the left in Figure 9 will be instrumented in the same way as the duct on the right, however, only the duct on the right will have a WHR device installed in the second bend of the duct. Appendix A shows a drawing detailing the locations of the new flanges and instrumentation locations that are going to be installed.

B. DEVELOPMENT OF A SOLIDWORKS MODEL OF THE EXHAUST DUCTS

When the Allison 250 gas turbine engine first came to NPS approximately 20 years ago, those engineers did not need electronic versions of the exhaust ducts. As such, there were no electronic versions detailing the exact geometry of the ducts. The current research started, therefore, by creating a 3-D SolidWorks model of the exhaust ducts using a tape measure and an inclinometer to ensure that NPS would have drawings of the existing exhaust ducts. Accuracy of the model design for the exhaust ducts was essential not only for construction purposes but also for the exhaust flow modelling in ANSYS.

Figure 10 shows the drawing produced to match the exact dimensions of the exhaust ducts shown in Figure 9. Dual exhaust ducts were initially modelled in the drawing just for reference. Only the exhaust duct on the right was further analyzed in the design of the WHR system.

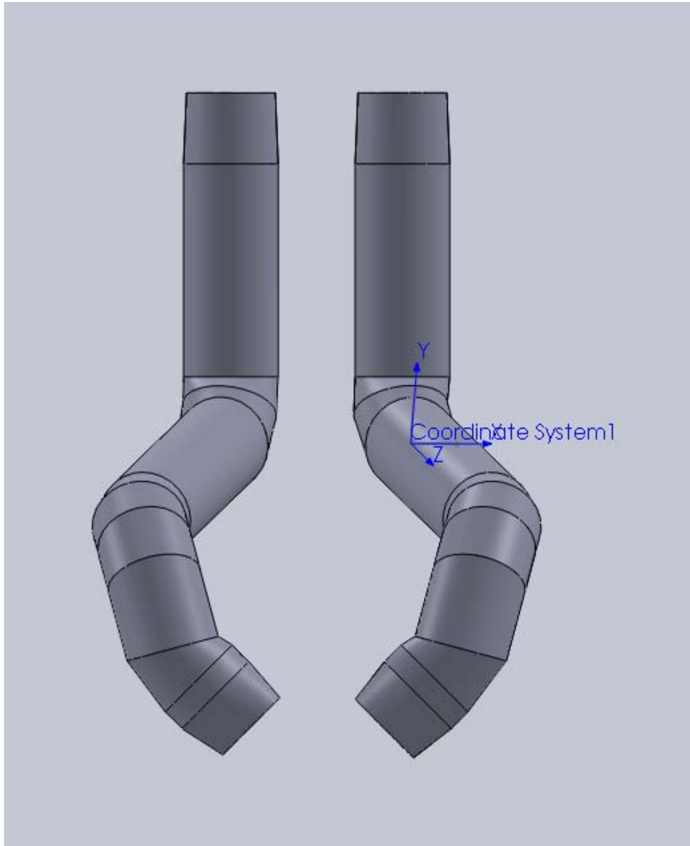

Figure 10. SolidWorks Drawing of the Dual Exhaust Ducts for the NPS Allison 250 Engine.

The singular exhaust duct, shown in Figure 11, was used to run all of the ANSYS baseline runs to validate the exhaust duct model with the actual known operating conditions of the engine. The researcher conducted baseline runs to determine the value of back-pressure that the standard exhaust duct placed on the engine. This back-pressure of the standard exhaust duct became the metric for the comparison of all variations of the exhaust duct.

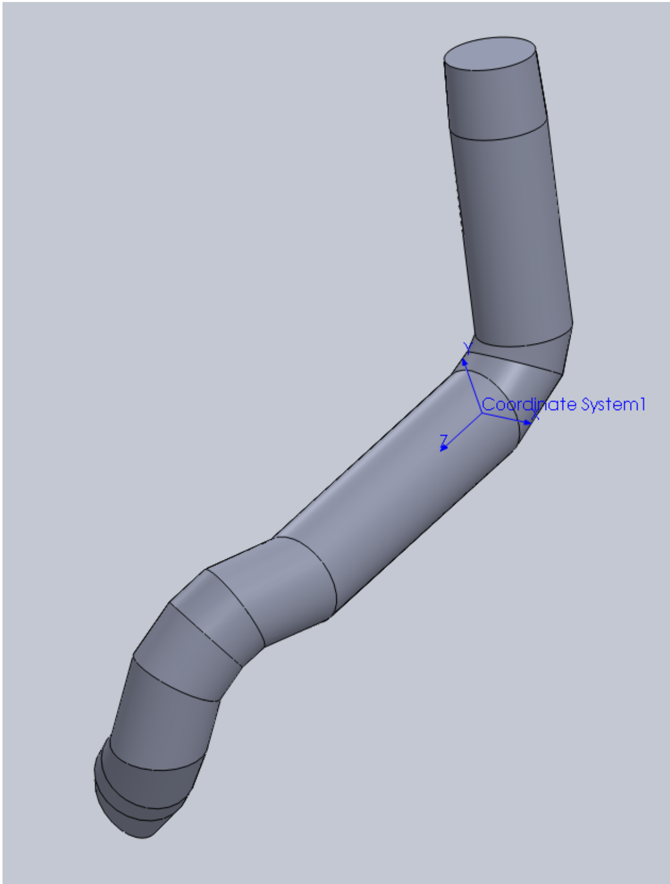

Figure 11. SolidWorks Drawing of a Single Exhaust Duct Used for Modelling in ANSYS.

C. ANALYSIS OF THE ALLISON 250 GAS TURBINE BEFORE OVERHAUL

Completing a full analysis of the Allison 250 gas turbine engine allowed the researcher to determine the effect that the age of the engine had on the performance. The Allison 250 turboshaft engine currently installed in the test cell of the marine propulsion lab was an old engine and had been slightly modified for prior research work. As such, the engine no longer operated near peak efficiency. The maximum power that the engine was supposed to be able to reach was around 246.1 kW (330 Hp). However, the engine only produced a maximum power of 149.14 kW (200 Hp). Knowing this, none of the engine data from the manufacturer can be used for the CFD models.

1. Calculations of the Engine Parameters from the Measured Operating Engine Data

The researcher decided to do a full operating run of the gas turbine at various engine loads and speeds to determine all of the engine parameters for this specific engine. Appendix B contains the raw data from this engine run. Most of the engine parameters were measured by the data acquisition software, but had to be organized and analyzed by the user.

As shown in Tables 1 and 2, the gas turbine engine achieved only a maximum power of 148 kW (198 Hp) during the operation and an efficiency of 32.2%, respectively. These values were used in the calculation of the other engine parameters located in Appendix B for the engine.

Table 1. Allison 250 Maximum Engine Operating Parameters in SI Units.

Turbine Inlet Temperature	Engine Power	Fuel Flow Rate	η – Thermal Efficiency
Celsius	kW	kg/hr	[-]
1139.943	147.723	73.004	0.322

Table 2. Allison 250 Maximum Engine Operating Parameters in Imperial Units.

Turbine Inlet Temperature	Engine Power	Fuel Flow Rate	η – Thermal Efficiency
Fahrenheit	Hp	lb/hr	[-]
2083.897	198.1	160.9	0.322

2. A GasTurb Analysis of the Engine Performance

The maximum values from the engine run were also used to compare results of the GasTurb software in order to try and determine the operating efficiencies of the compressor, high pressure (HP) turbine and the power turbine. The researcher ran the program iteratively, while varying the efficiencies for each of the units until the output values were as close a match to what the actual engine performance data shows at full load.

The GasTurb software can be used to explain why the engine could no longer reach maximum power. Figure 12 shows the numbered data points where GasTurb solved the various temperatures and pressures inside the engine. Appendix C contains the raw data output file for this run. In order to match the engine parameters as closely as possible, the efficiencies of the compressor, HP turbine, and power turbine had to be set at 65%, 82% and 85%, respectively. This showed that, through the turbine's many years of service, the components inside the engine, mostly the compressor, had been badly degraded.

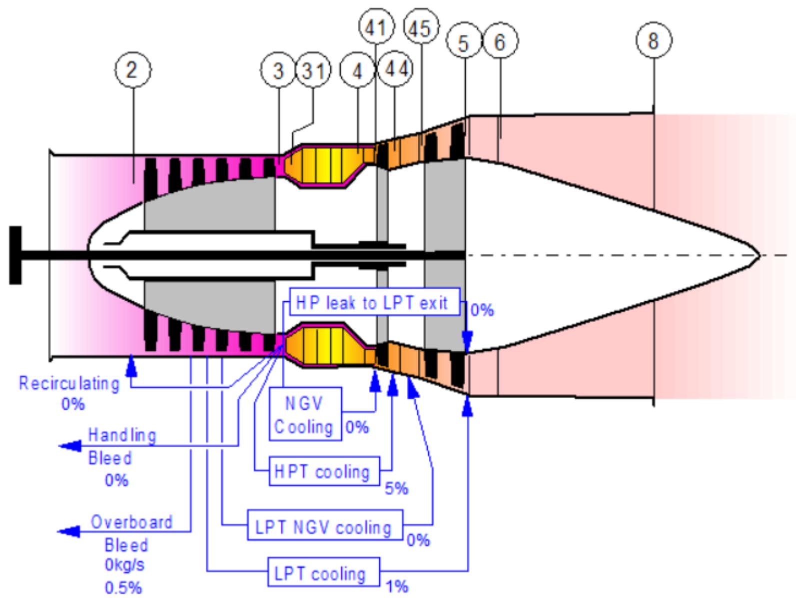

Figure 12. GasTurb Layout of a Turboshaft Gas Turbine Engine Used for the Analysis of the Allison 250 Engine.

The GasTurb software contains many built in features designed to assist engineers in analyzing gas turbine engines. The Temperature Entropy (T-s) diagram in Figure 13 also shows the condition of the compressor between points 1 and 3. The angle of the slope indicates that the compressor was operating at a condition far from the isentropic ideal compressor that was sought. The ideal compressor would have a vertical line between points 1 and 3 on the diagram.

The turbines in the T-s diagram also show some degradation from their age. The high pressure turbine is shown between points 4 and 43 and the power turbine is shown between points 44 and 8. Ideal isentropic turbines would have vertical lines on the T-s diagram much like the ideal compressor would. The slopes of the lines for the turbines also demonstrate the lower thermodynamic efficiency of each turbine.

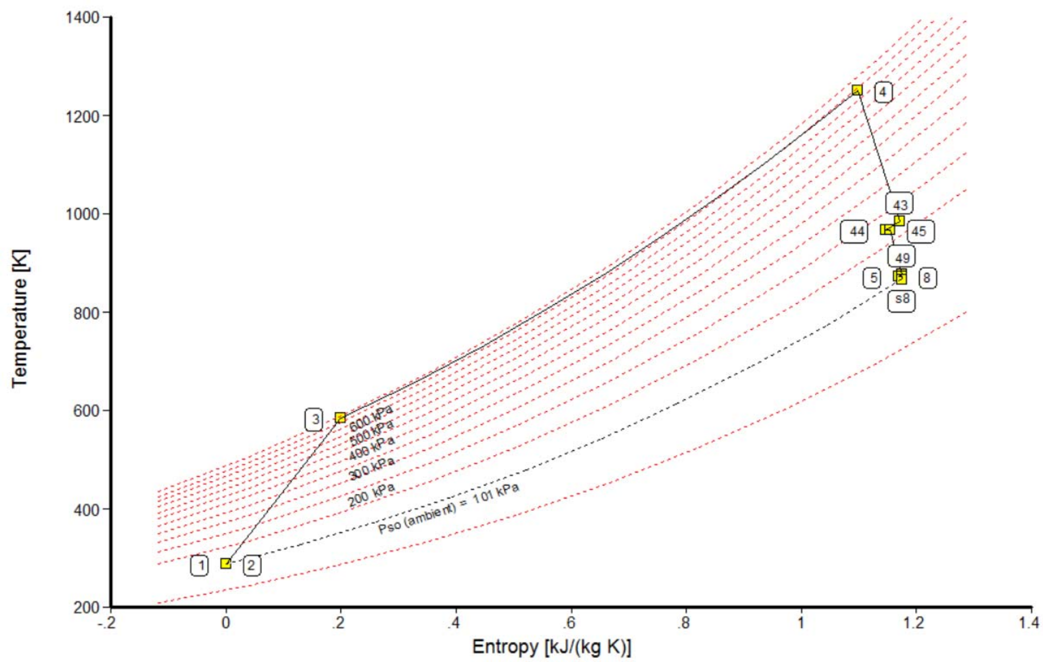

Figure 13. Temperature Entropy Diagram Created in GasTurb for the Analysis of the Allison 250 Gas Turbine.

Another useful analysis feature of the GasTurb program is the ability to simulate a full operating line for the engine to see how the compressor and turbines perform at various engine speeds. Figure 14 shows the operating line created using GasTurb and plotted on the compressor map for the Allison 250 engine. Each of the red dotted lines in Figure 14 represents a line of constant thermodynamic efficiency.

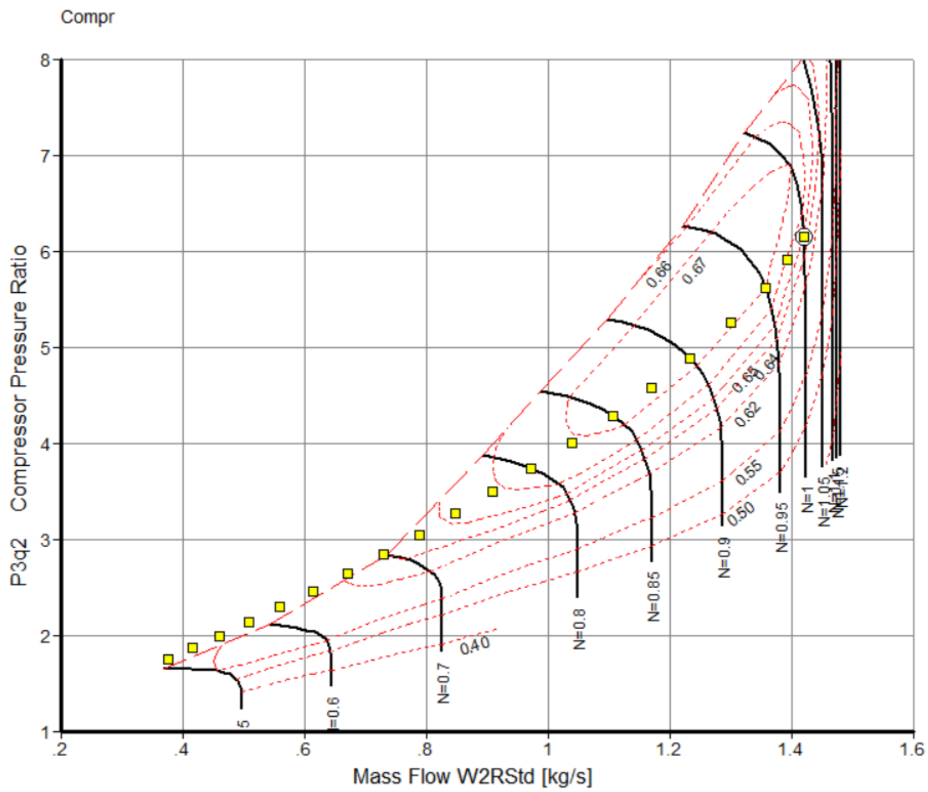

Figure 14. GasTurb Analysis of an Operating Line Plotted on the Allison 250 Compressor Map.

Normally, efficiently operating engines have the operating line pass through the area designated on the map as the most efficient area of operation for the compressor. In this case, that area is located inside the dotted line labeled 0.67. The speed line shows that for the maximum power, the far right dot surrounded by white, misses the area of maximum efficiency. The speed line also only passes through this section briefly as the engine speed and power are decreased. This demonstrates that the compressor in its current state can no longer perform the way that it was intended to.

The GasTurb software also enables the user to create graphs of various engine parameters. Figure 15 shows a GasTurb generated plot of the power specific fuel consumption of the engine vs. the specific power for the same operating line from Figure 14.

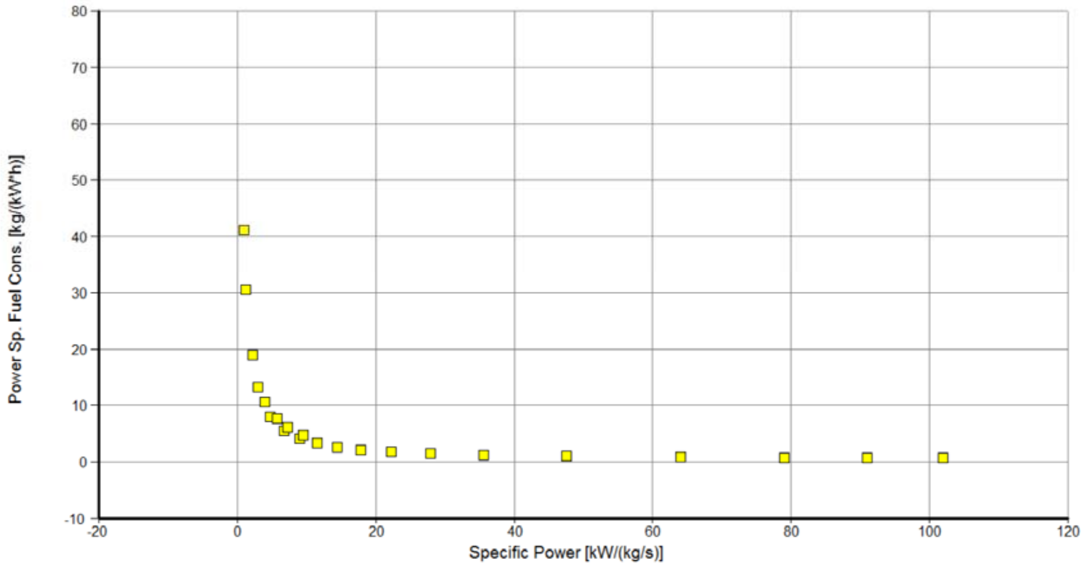

Figure 15. GasTurb Plot of Specific Fuel Consumption vs. Engine Specific Power for the Allison 250 gas Turbine.

Being able to understand how the power specific fuel consumption varies with engine specific power is a useful tool in analyzing the engine. The plot in Figure 15 shows that the engine would consume about the same amount of fuel per kW while the engine produced between 20kW and 105kW. However, when the engine power output drops below 20kW, the specific fuel consumption rises drastically. This fuel consumption rise was because at lower operating power and at idle, the engine requires more fuel per kW to operate than when the engine is at full load. This is why the engine operates more efficiently at higher loads as shown in Figure 14.

All of the analysis tools that were utilized showed that the Allison 250 gas turbine engine in the NPS lab was severely degraded. However, the engine was still fully operational. Therefore, the researcher determined that the engine was suitable for use as a test bed for the WHR heat exchanger design and that the data obtained from the testing could be used in ANSYS for the fluid flow models.

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III. ANSYS MODELING TO DEVELOP THE HEAT EXCHANGER DESIGN

Designing a new style of heat exchanger would not be possible without all of the knowledge of the engine shown in Chapter II. This information on the temperatures, pressure, and efficiencies of the engine allows enough to be known about the exhaust that is exiting the engine. This knowledge in turn allows the boundary conditions in ANSYS to be set up properly to solve the flow and analyze the results.

A. INITIAL RUNS ON EXHAUST DUCT TO DETERMINE BACK-PRESSURE

The first step in the process of designing a new style of WHR heat exchanger for the Allison 250 gas turbine engine was to take the single modelled exhaust duct and run it through ANSYS to determine the back-pressure through the exhaust duct. The boundary conditions that were used for the first few runs to model the exhaust flow were the inlet temperature and pressure and the outlet pressure. The inlet temperature was set to 750K (890°F) and the inlet pressure was varied to attempt to match the mass flow from ANSYS to the mass flow measured in the engine. The outlet pressure was set to an atmospheric pressure of 101,350Pa (14.7psia). This initial set of boundary conditions did not determine the mass flow exactly; the closest that ANSYS was able to solve for was 0.68kg/sec (1.5lbm/sec). The inlet boundary conditions were then set to specify the inlet temperature and the inlet mass flow of 0.71kg/sec (1.57lbm/sec). These new boundary conditions allowed the flow to be set and for ANSYS to determine the back-pressure through the exhaust duct.

1. Determining the Ideal Number of Inflation Layers for the Exhaust Duct

Inflation layers are important because they allow the mesh to have more data points, or nodes, close to the walls. The data points near the walls allow ANSYS to obtain a more accurate solution for the boundary layers of the flow. Determining how many inflation layers should be set in ANSYS is an efficient step to pinpoint the number of nodes that the program would have to solve. This task involved running the same flow parameters through the single exhaust duct and checked the average value of Y+ for each run:

$$Y+ = \frac{yu^*}{\nu}, \tag{7}$$

where

$$u^* = \sqrt{\frac{\tau_w}{\rho}}. \tag{8}$$

The Y+ term is a non-dimensional distance away from the pipe wall in a boundary layer, allowing for all flows to have the same distance definition for the boundary layers. Single digits of Y+ indicate that the first grid point away from the wall is within the laminar sub-layer of the turbulent boundary layer. The u* term is a non-dimensional velocity like quantity, which is normally called the wall-friction velocity [14].

Table 3 shows the raw data collected from ANSYS while varying the number of inflation layers along the wall of the exhaust duct.

Table 3. Various Parameters for the Solution of the Exhaust Duct While Varying the Number of Inflation Layers.

Number of Inflation Layers	Pressure Difference (Pa)	Y+	Number of Grid Points	Time to Solve (seconds)
10	328	68.6494	1697162	790.804
20	323	10.067	3077941	1476.21
30	247	1.59584	4463879	2189.42
35	102	0.636476	5154870	1304.91
40	9	0.25526	5846797	1470.553

This data table alone did not clarify which of the options was the best. The values were then all normalized by dividing each value in each column by the maximum value in that column; allowing all of the data to be plotted onto one graph. The plotted normalized values are shown in Figure 16.

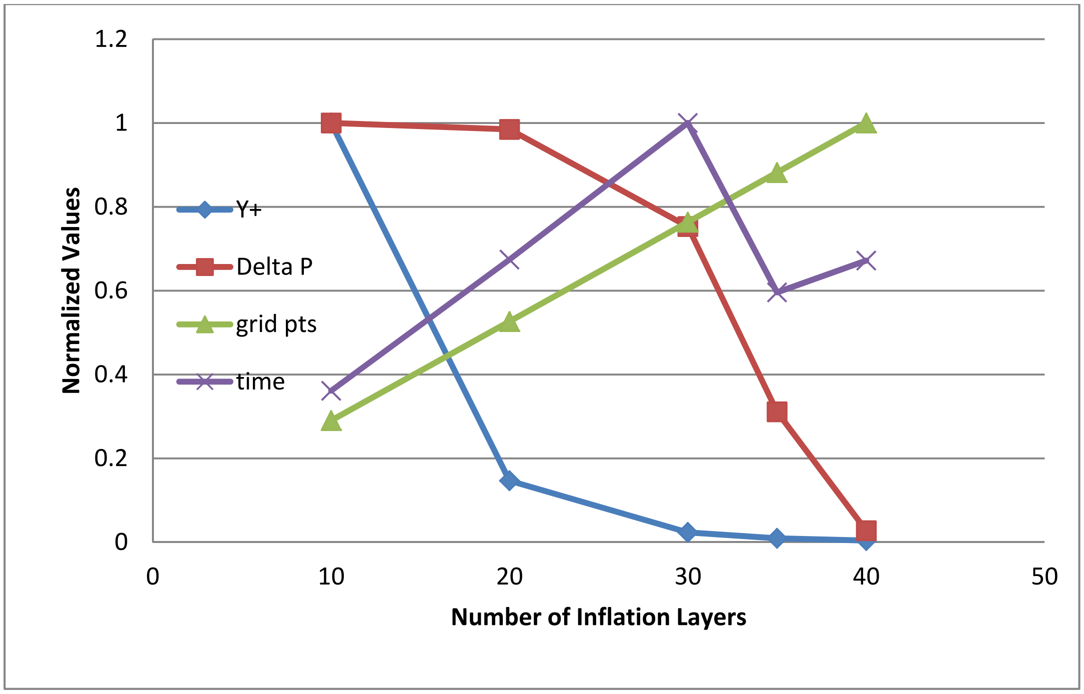

Figure 16. Number of Inflation Layers Plotted Against Various Normalized Parameters for the ANSYS Exhaust Duct Solution.

The plot in Figure 16 showed that there were an optimal number of inflation layers for solving the exhaust duct flow. The blue curve with diamond points is the normalized Y+ values. This curve should be a minimum for the optimal number of inflation layers. This curve also exhibits the shape of an exponential decay plot that begins to level out around the 17 layer mark. The other main curve used to determine the optimum number of layers was the time to solve line shown in purple with star points. This curve appears to be semi-linear but has a dip above 30 inflation layers. The red curve shows the normalized values that ANSYS estimated as the pressure drop across the exhaust duct. As expected, the differential pressure drops as the number of inflation layers increases. This differential pressure drop is due to the fact that the solution near the exhaust duct wall is more defined when there are more inflation layers. The differential pressure curve and the time to solve curve cross at 18 inflation layers.

When an ANSYS run with 18 inflation layers was attempted, no solution was found. The simulation faulted out prior to starting iteration 1. Since ANSYS would not solve using 18 inflation layers, it was decided that using 17 inflation layers would give an excellent approximation of Y+ values for the flow and would still be in the region of shorter run times.

Figure 16 also shows the relationship between the solved for back-pressure given by each run according to the number of inflation layers. This line is shown in blue with diamond points. The back-pressure that ANSYS estimated when using 17 inflation layers was 102317Pa (14.84psi). This back-pressure became the target for the modified exhaust duct and waste heat exchange not to exceed.

2. Analyzing the Flow through the Circular Exhaust Duct while Using 17 Inflation Layers

Once the number of inflation layers was determined, the flow through the exhaust duct was analyzed to determine how turbulent the flow was and if there were any areas of separation. This analysis is critical to help design the new heat exchange to fit in the flow and not cause a rise in the back-pressure on the engine.

ANSYS has the ability to calculate and visually demonstrate many of the characteristics of the flow, simplifying the analysis. Figure 17 shows a color contour plot of the variations in the velocity of the exhaust gas as it travels through the duct.

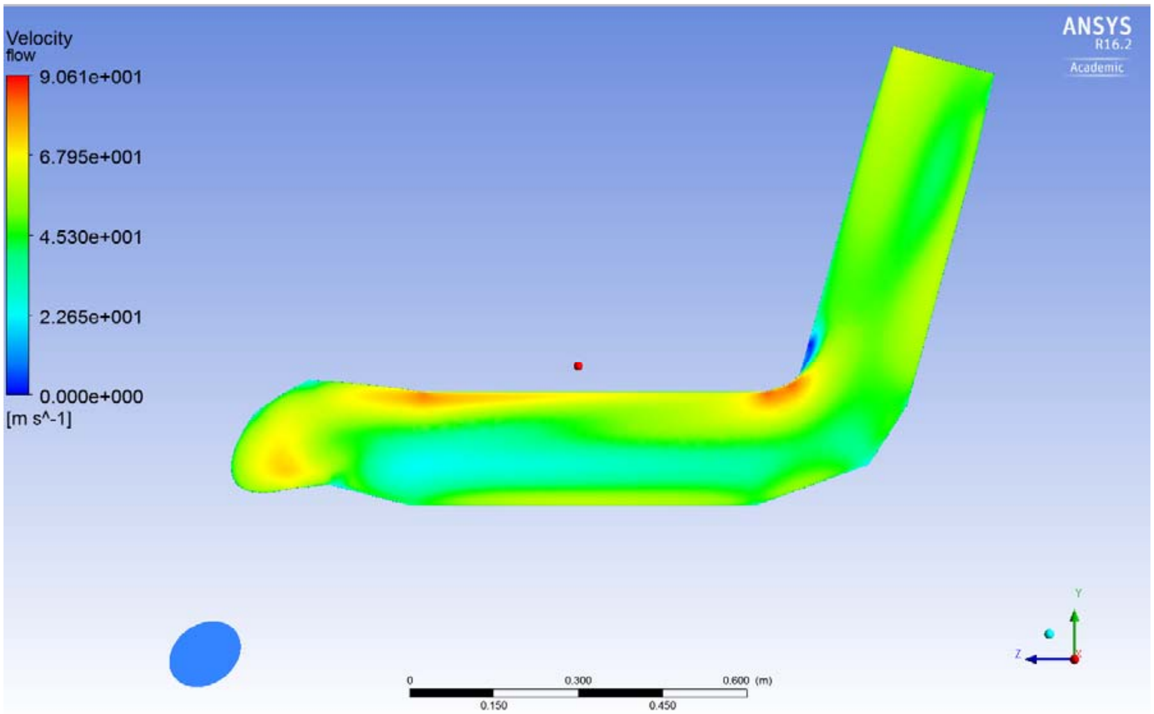

Figure 17. Contour Map of Variable Velocity for Circular Exhaust Duct.

Figure 17 shows a contour map that visualizes of the selected variable, velocity, through the domain. In this case, the contour varies with the velocity in the duct, dark blue for slow velocities and red for high velocities. Since the new heat exchanger will ultimately be located in the second bend of the duct, that area is where the focus of the analysis was conducted. The small red section at the apex of the bend indicates that the flow accelerates as it travels around the bend. Figure 18 is an enlarged image of that bend to visualize what the flow is doing.

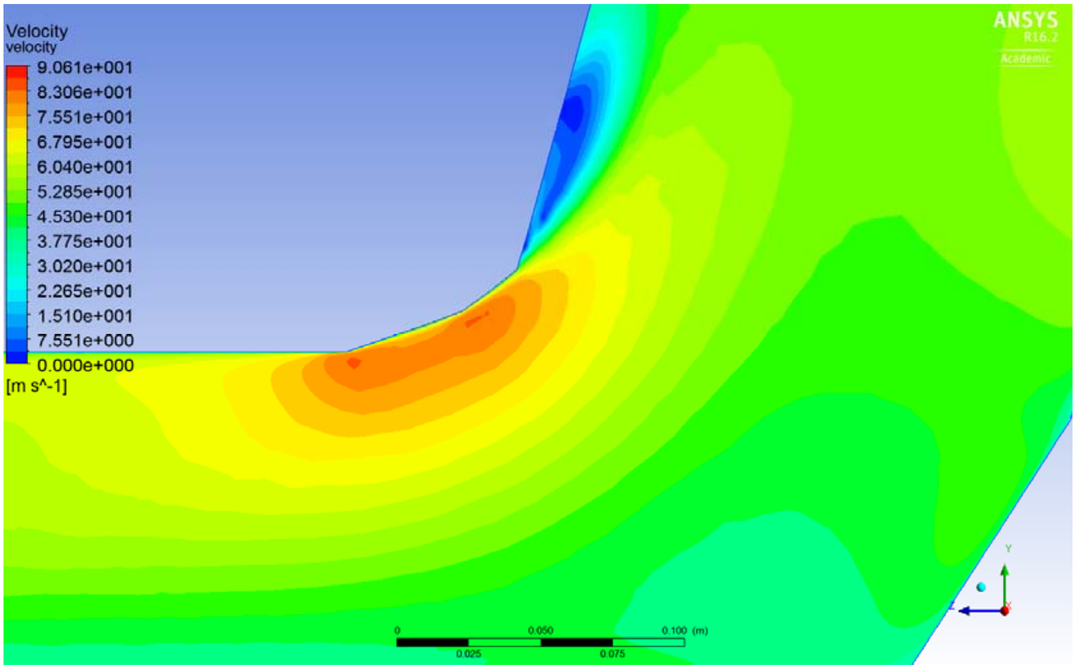

Figure 18. Enlarged View of the Second Bend on the Circular Exhaust Duct.

This larger view allows for a more thorough analysis of the flow through the bend. The red area of higher velocity quickly transitions to blue at the corner where the duct bends to 80. This small recirculation zone is an indication that the flow cannot make the turn around the bend without the boundary layer separating from the exhaust duct wall. This separation causes the flow to reverse direction and create an area of vorticity in the flow. The outer edge of this separation zone acts like a wall, causing the flow to accelerate even more through the bend. This highly turbulent phenomenon creates an increase in the drag of the exhaust duct and an increase in the back-pressure on the engine.

Viewing the velocity contours in two dimensions (2-D) works well for viewing the flow; however, being able to fully analyze the flow requires a 3-D image. ANSYS is able to create a 3-D view using streamlines. A streamline is a line in the flow of constant velocity. Therefore, the streamlines will follow the ever-changing exhaust flow by mapping out the areas that have a constant speed. Figure 19 shows this type of imagery for the circular exhaust duct.

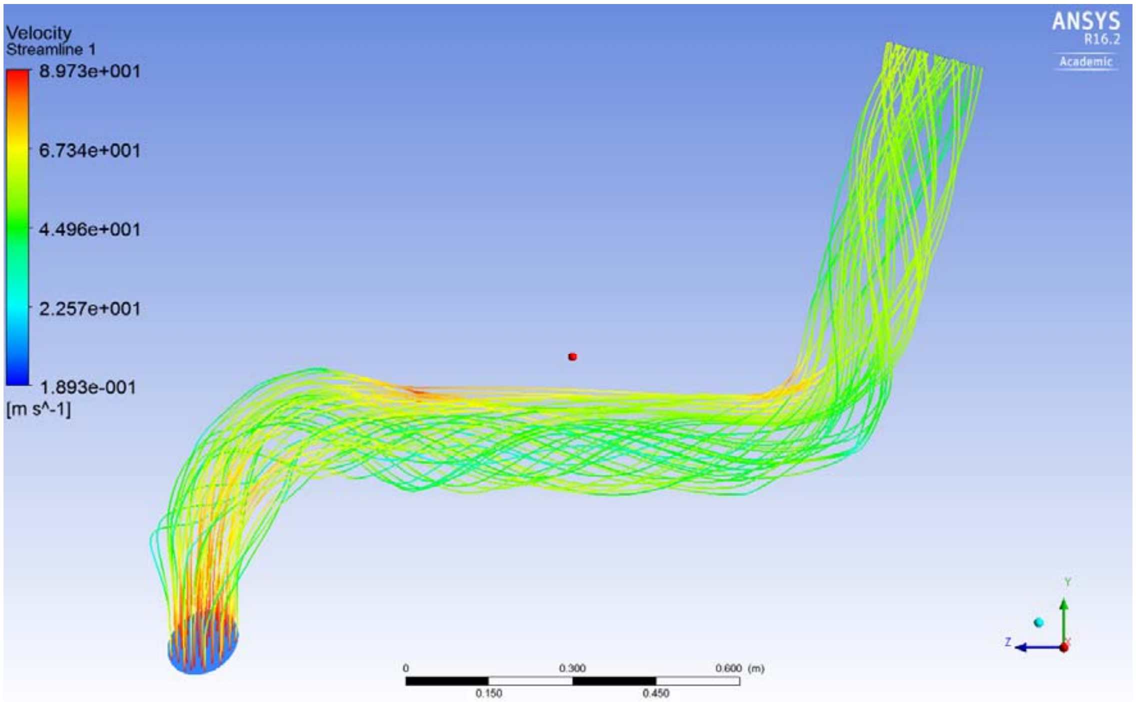

Figure 19. ANSYS Streamline Depiction of the Exhaust Flow through the Circular Exhaust Duct.

Turbulence in a fluid flow is both useful and a hindrance. An ideal laminar flow through this exhaust duct would have all of the streamlines parallel to each other and the walls of the exhaust duct. The apparent randomness of the streamlines in the Figure 19 demonstrates this turbulence in the flow. The turbulence causes the drag of the exhaust duct piping to decrease, but it also causes an increase in the back-pressure by the separation areas within the flow. In many cases, turning vanes are used in and around bends to assist the flow through the bend to reduce the separation areas and backflow within an exhaust duct. This addition reduces the back-pressure on the engine and increases efficiency.

B. REDESIGNING THE SECOND BEND OF THE EXHAUST DUCT AND ANALYZING THE FLOW

The baseline runs were completed to determine the original back-pressure on the engine. However, when a heat exchanger is placed inside an exhaust duct bend, the duct should be modified. The modification, in this case, was an increase in the cross-sectional area of the duct. This increase offset the loss in area that accompanies inserting the heat exchanger tubes into the flow. Figure 20 shows the modified exhaust duct.

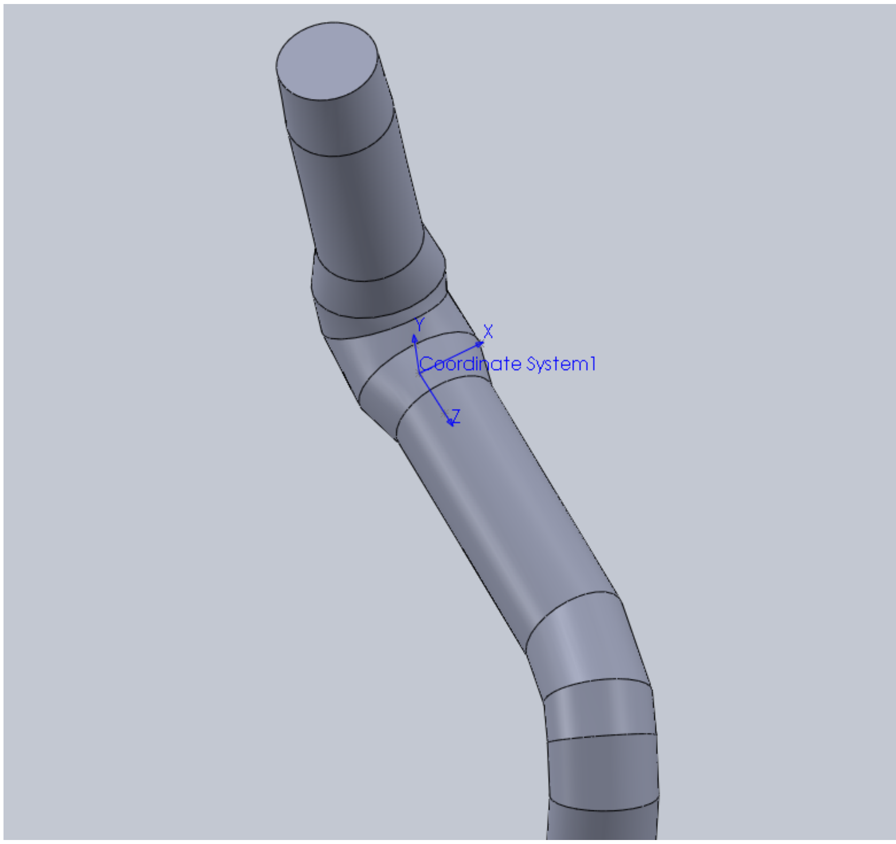

Figure 20. Modified Exhaust Duct with Ovular Design for the Second Bend.

The original duct was constructed of thin stainless steel tubing with an inner diameter of 0.2m (8inches). This new design consisted of a 0.1m (4inches) long section that transitioned from the circular cross section to an ovular cross section with a major diameter of 0.25m (10inches) and a minor diameter of 0.2m (8inches). This new ovular cross section design increased the cross sectional area by 0.0047m^2 (6.28inches^2).

The redesign of the exhaust duct was necessary to ensure that the flow area would remain nearly constant when the heat exchanger was added. However, changing the cross sectional design of the exhaust duct also changed the flow features of the exhaust gas within the duct. The baseline runs using the circular cross sectional duct were repeated with the redesigned duct to compare the results. The boundary conditions and the number of inflation layers used remained constant to obtain a good comparison between the ducts.

Figure 21 shows the flow through the new ovular duct shown on the same plane cut as in Figure 17. This visualization allows for a side-by-side comparison for any differences in the flow of the exhaust.

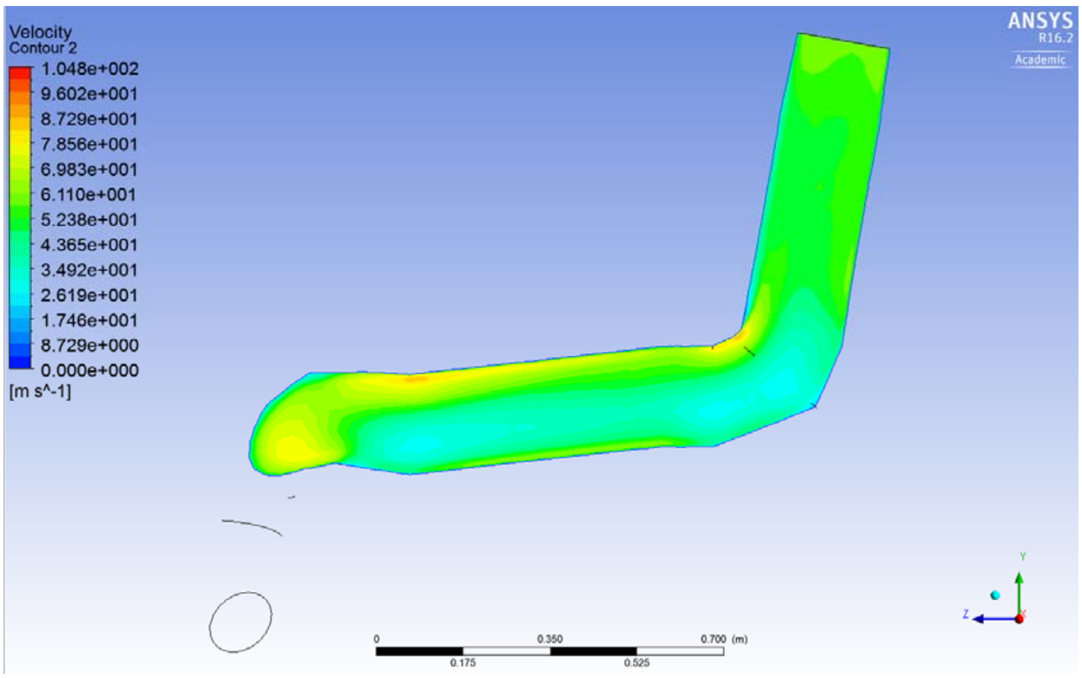

Figure 21. Contour Map of Variable Velocity for Ovular Exhaust Duct.

Figure 21 shows much less variation in the exhaust velocities through the second bend than Figure 17 showed for the original duct. The recirculation area at the top of the bend has become smaller with just adjusting the width of the exhaust duct. The exhaust duct velocity distribution seems to show a more uniform flow field than the circular duct. However, Figure 22 shows the streamline depiction of this flow to be just as random and turbulent as the circular duct appeared to be.

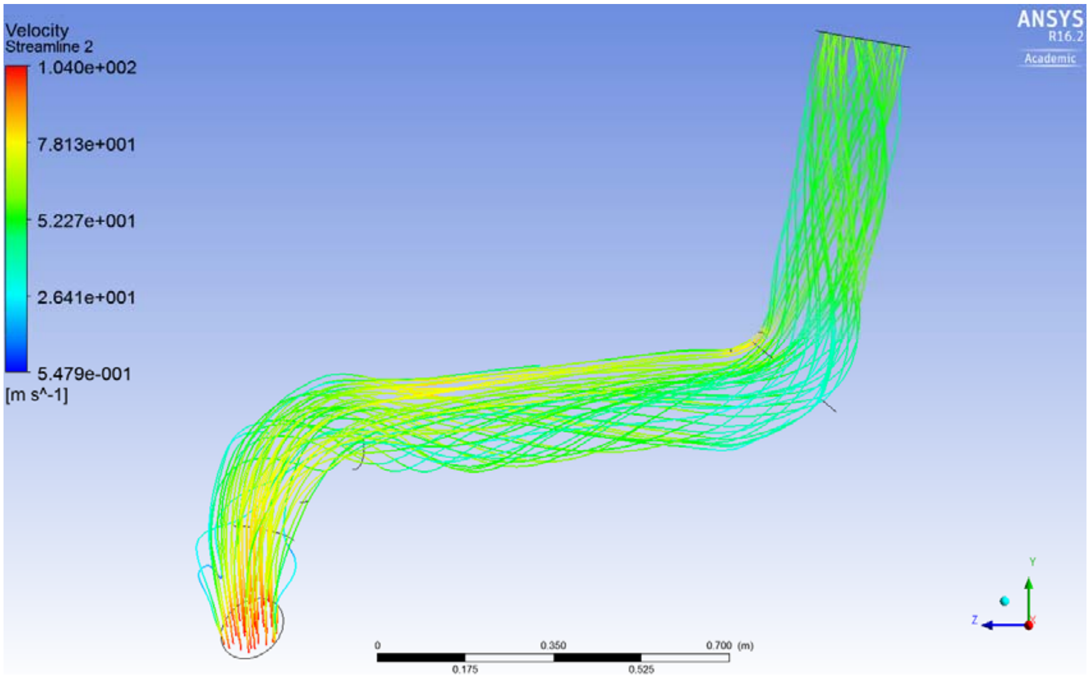

Figure 22. ANSYS Streamline Depiction of the Exhaust Flow through the Ovular Exhaust Duct.

Even though Figure 22 shows the flow to remain highly turbulent, as expected, the change in cross-section did have an effect on the back-pressure of the engine. ANSYS estimated that the back-pressure from this exhaust duct model would place 102165Pa (14.82psi) on the engine. While this change is only a 0.15% reduction in the back-pressure on the engine, this reduction showed that the modified exhaust duct would be able to handle the insertion of a heat exchanger without overly increasing the back-pressure above the original baseline values. This result initiated the design phase for the heat exchanger using the ovular exhaust duct.

C. FIRST ITERATION DESIGN OF THE EXHAUST DUCT HEAT EXCHANGER

The first design iteration of the heat exchanger for the ovular bend of the exhaust duct was created using approximately equally spaced tubes in the shape of three turning vanes. The idea behind this design stems from extracting heat from the exhaust gas while simultaneously assisting the flow through the bend without increasing the back-pressure on the engine. Figure 23 shows the SolidWorks model of the newly designed heat exchanger in the ovular duct.

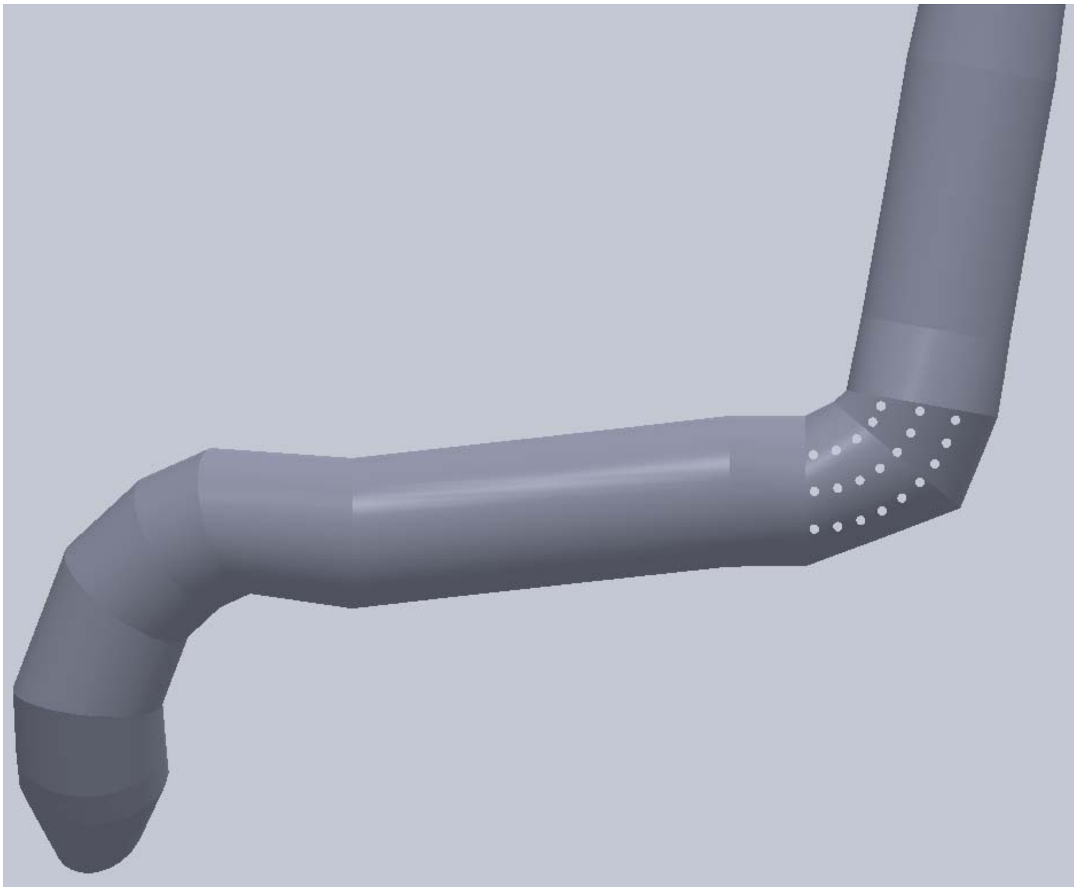

Figure 23. SolidWorks Model of the First Iteration for the Heat Exchanger Design.

The design in Figure 23 utilizes 21 heat exchanger tubes arranged in three arcs analogous to turning vanes. The tubes in the design were 0.0127m (0.5inch) diameter and spaced approximately 0.051m (2 inches) apart center-to-center. The top row of tubes was spaced 0.051m (2 inches) below the top of the duct. The lower two rows were spaced 0.51m (2 inches) below the row above them. This spacing allowed the three rows of tubes to be equally spaced in the exhaust duct. The last tube of each tube row is also spaced 0.051m (2 inches) apart. The design using three equally spaced rows of tubes was based on Mark A. Beale's work summarized in Chapter I [12].

Once the design for the heat exchanger had been created, the researcher used ANSYS to model the flow through the duct and around the tubes. Figure 24 shows the contour map of the velocity variations through the duct and around the tubes.

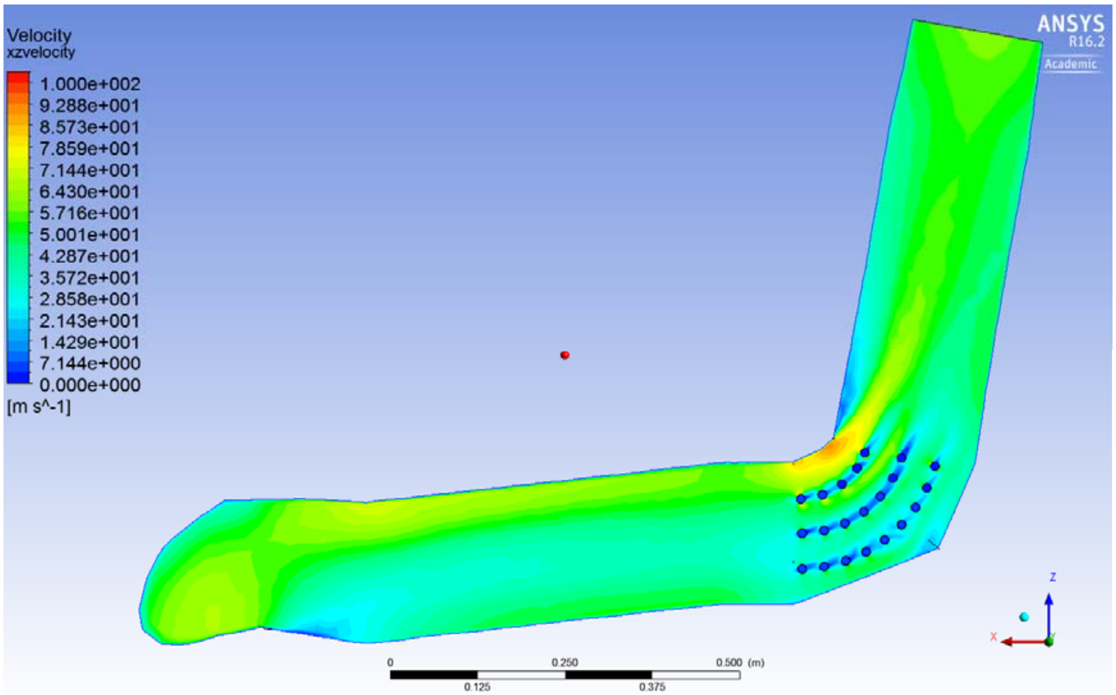

Figure 24. Contour Map of Variable Velocity for the Ovular Duct with Heat Exchanger Tubes.

This contour map of the velocity shows that a good portion of the flow moves at higher velocities between the tube wall and the top row of tubes. There is also a smaller amount of flow that travels between the top two rows of tubes. These groups of higher local velocities demonstrate the tubes behaving like turning vanes as designed. The separation zone in this iteration is larger than it was without the tubes, but still more compact than the original circular exhaust duct.

The ANSYS streamline view was also used in the analysis. Figure 25 shows this streamline view. The streamlines show that the flow was being turned by the layout of the tubes. This turning confirms the theory that a tube bank in a heat exchanger can be properly designed to assist the flow through a bend.

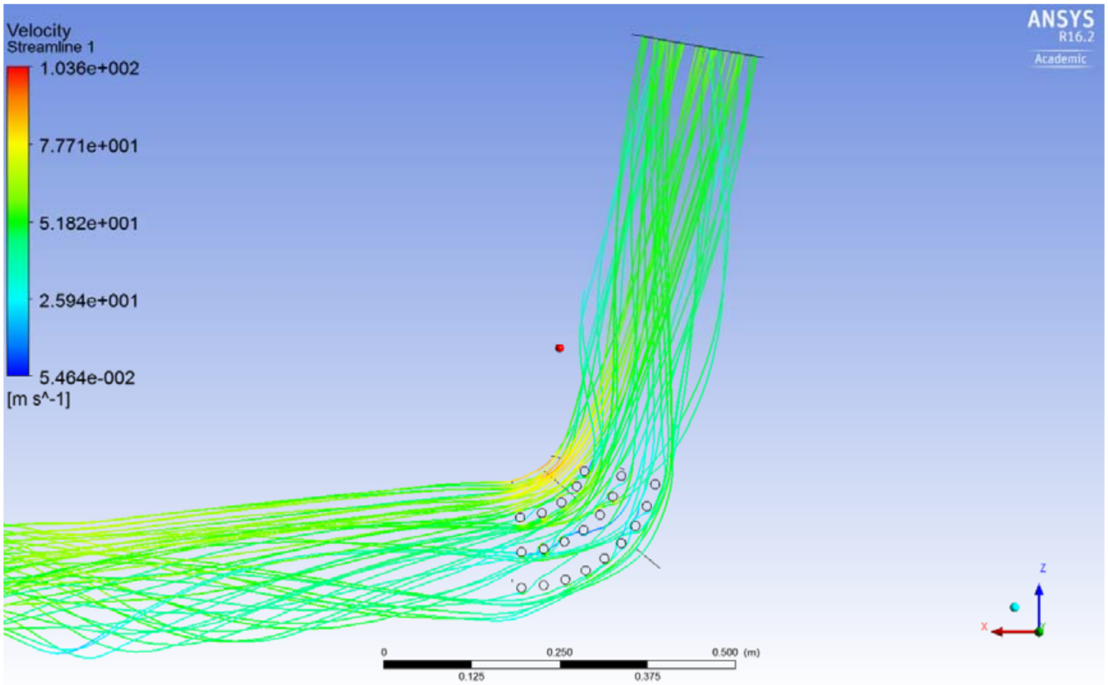

Figure 25. ANSYS Streamline Depiction of Exhaust Flowing Around the Heat Exchanger Tubes.

Most of the streamlines in Figure 25 are between the top row of tubes and the top wall of the duct as expected. These streamlines also appear to exit the bend and travel in a straighter path to the exit of the exhaust duct. This demonstrates the effectiveness of the tubes flow-turning ability. Since the recirculation area had grown slightly, the back-pressure on the engine was expected to have increased slightly as well. ANSYS estimated that the back-pressure on the engine with this heat exchanger design in the bend was 102272Pa (14.83psi). This pressure increased slightly from the back-pressure of the ovular duct without tubes. However, the back-pressure remained below the value for the original circular exhaust duct.

D. REFINING THE HEAT EXCHANGER DESIGN TO MAXIMIZE HEAT EXCHANGE

The first iteration heat exchanger confirmed the idea that the tubes can be laid out in such a way as to behave like turning vanes in the flow. However, there a tradeoff existed between the number of tubes and the amount that the back-pressure increases on the engine. A more ideal heat exchanger would have many more tubes than the 21 in the first iteration design. The more tubes placed in the flow; however, the more back-pressure will be increased on the engine.

1. Second Iteration Design of the Heat Exchanger

In order to attempt to reduce the recirculation area of the exhaust duct, the ovular cross section was continued past the bend and up the straight portion of the exhaust duct 0.1m (4inches). This new design placed tubes in this portion in a straight line following the tubes in the bend. The location of these new tubes attempted to get the flow exiting the bend to continue in a straighter path to the exit of the duct. An added benefit of these additional tubes produced more surface area for heat exchange within the exhaust duct. In theory, these modifications will assist the flow better and also be able to extract more heat from the exhaust.

Figure 26 shows the redesigned exhaust duct with the larger heat exchange in the second bend. The top row of tubes received three more tubes and the second and third rows of tubes received four more tubes each. The second and third rows of tubes also gained one additional tube each in order to decrease the average spacing between the tubes. The dimensions of the newly added tubes were identical to the original tubes. However, the additional 13 tubes combined with the original 21 tubes added up to a total of 34 tubes for heat exchange and flow-turning.

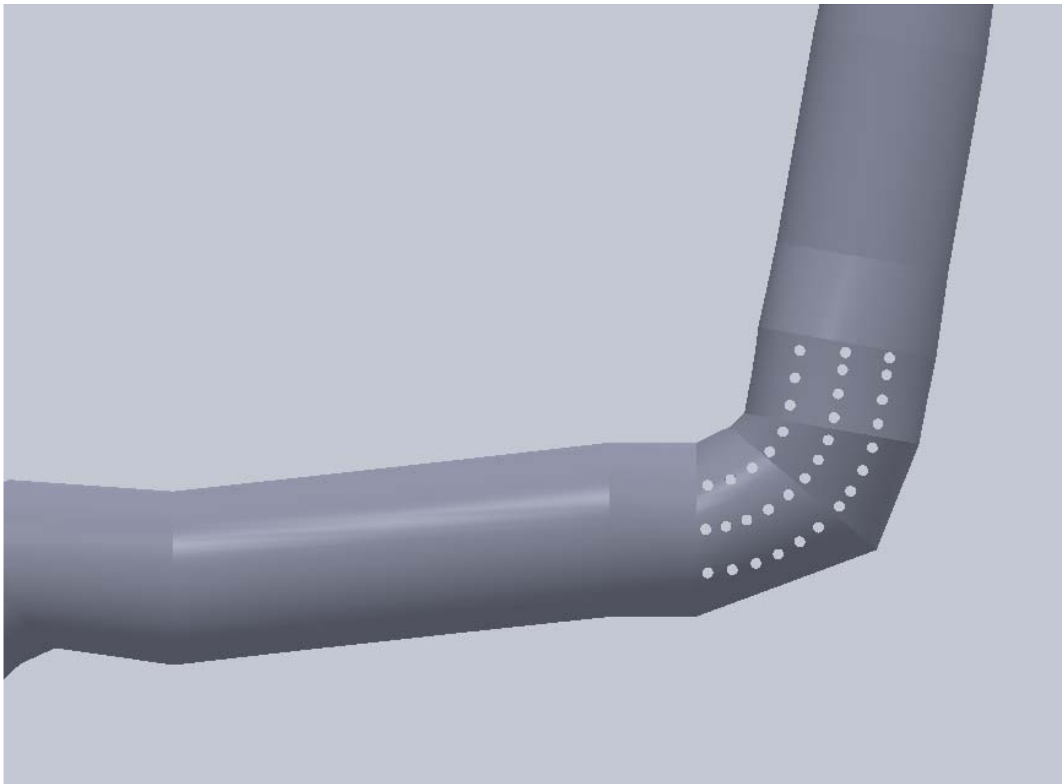

Figure 26. Ovular Exhaust Duct Heat Exchanger Design with Extended Tube Rows for Added Heat Exchange.

The researcher ran the modified exhaust duct WHR design in ANSYS to determine if these new tubes made any difference in the flow of the exhaust gas. The boundary conditions used to solve this exhaust duct design remained constant from each prior iteration. Figure 27 shows the contour map for the velocity variations in the exhaust duct.

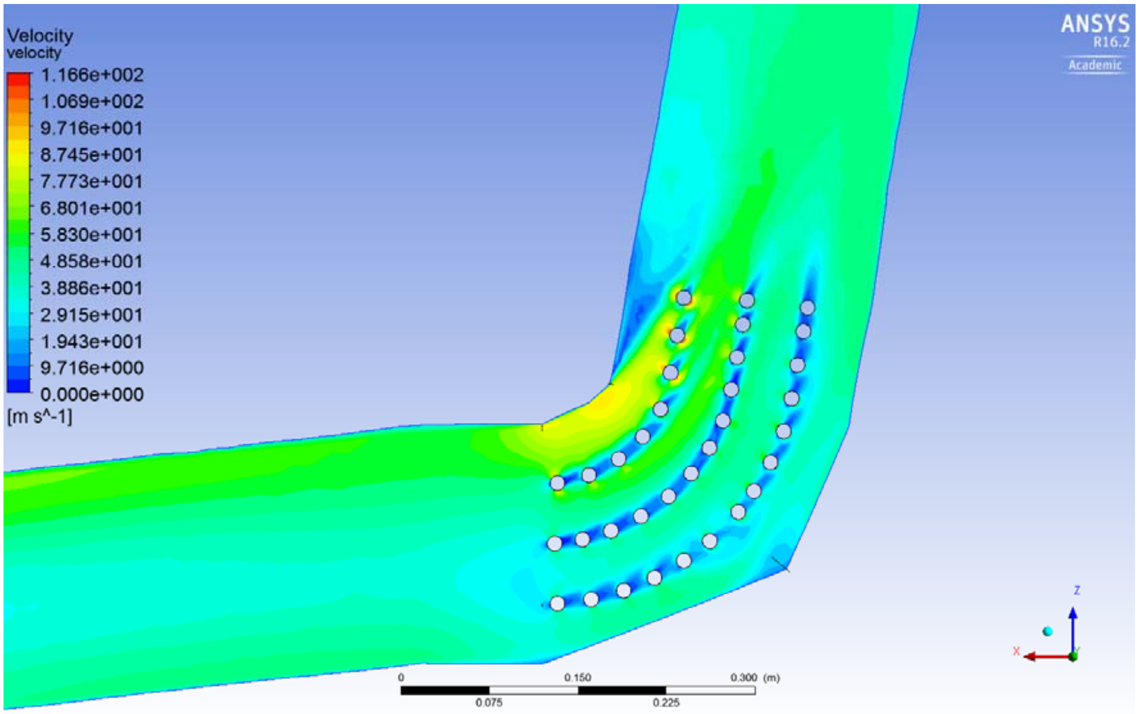

Figure 27. Contour Map of Variable Velocity for the Extended Heat Exchanger Design.

The contour mapping in Figure 27 shows that the exhaust flow through the upper portion of the bend does not continue to follow the new tubes in the top row. The flow appears to travel between the tubes and mix with the flow travelling between the top and middle rows of tubes. This new mixing of flows has also increased the size of the recirculation area inside the duct to almost fill the entire gap between the duct wall and the top row of tubes. This phenomenon causes almost no flow to move towards the exit of the duct in this region. Figure 28 shows the ANSYS streamline view of the same area for a 3-D view of the flow movement.

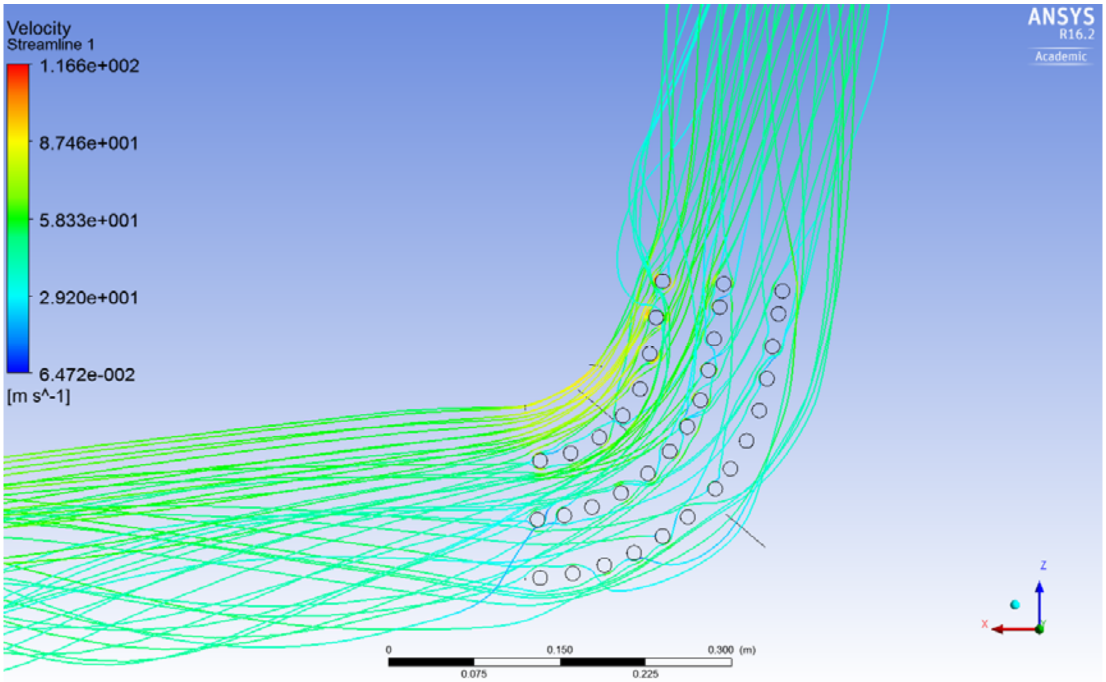

Figure 28. ANSYS Streamline View of the Extended Heat Exchanger showing Mixing of Flow Streams.

The streamlines in Figure 28 also show flow travelling between the tubes in the top row and mixing with the flow paths of the exhaust gas. This mixing causes more turbulence in the flow, which leads to more back-pressure being placed on the engine. The flow moving between the tubes also eliminates the effectiveness of placing the tubes in a turning vane style layout by not following the direction of the tubes. ANSYS estimates the back-pressure from this layout and flow pattern to be 102490Pa (14.87psi). This back-pressure value is greater than the back-pressure of the original circular exhaust duct, but it does not cause enough of an increase to cause any major performance degradation of the engine.

2. Final Design of the Heat Exchanger for the Exhaust Duct

The flow between the tubes was a highly undesirable situation to have occurring in the flow field, since this erratic flow movement typically causes increased back-pressure. Therefore, the WHR design was modified slightly in order to prevent as much of the flow from going between the tubes as possible. The modification only affected the top row of tubes; the other two rows of tubes remained unchanged. Two tubes were added into the straight portion of the tube row in order to reduce the spacing between the tubes. This small change in the spacing of these tubes reduced the area between the tubes, which should reduce the amount of exhaust flow that can traverse the gaps. Figure 29 shows the final design of the exhaust duct heat exchanger with the modified top row of tubes.

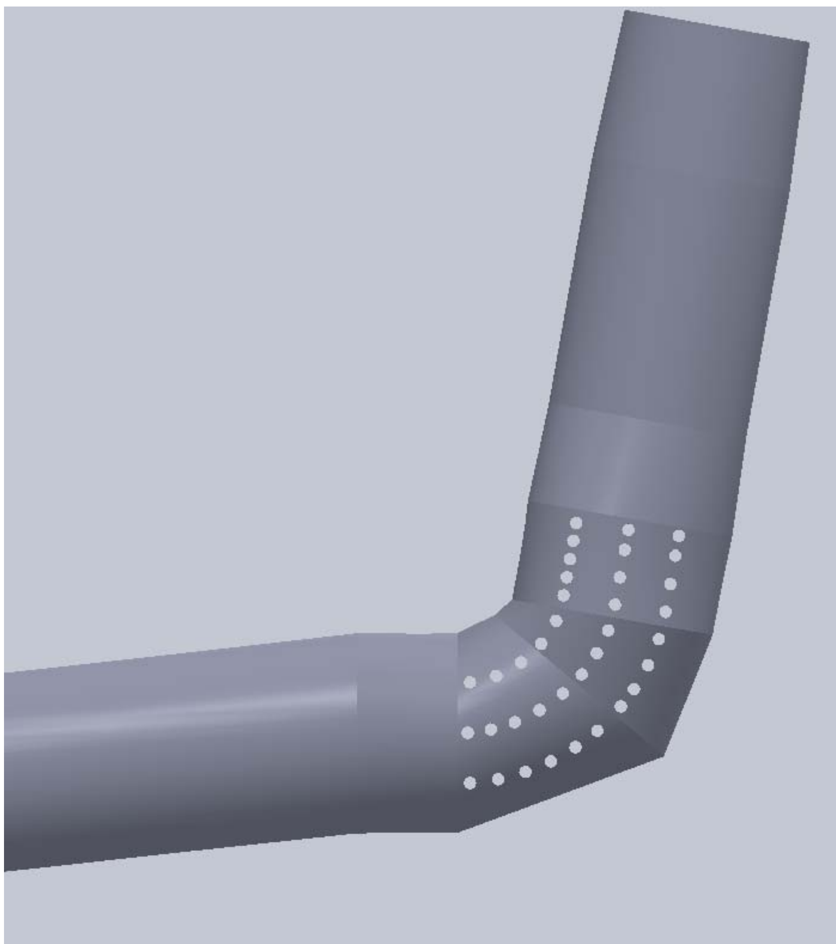

Figure 29. SolidWorks View of Final Design for Exhaust Duct Heat Exchanger.

The researcher ran this modified exhaust duct through ANSYS to determine whether closing the gap between the tubes in the top row had made any difference. Figure 30 shows the velocity contour map of the exhaust gas flow around the tubes.

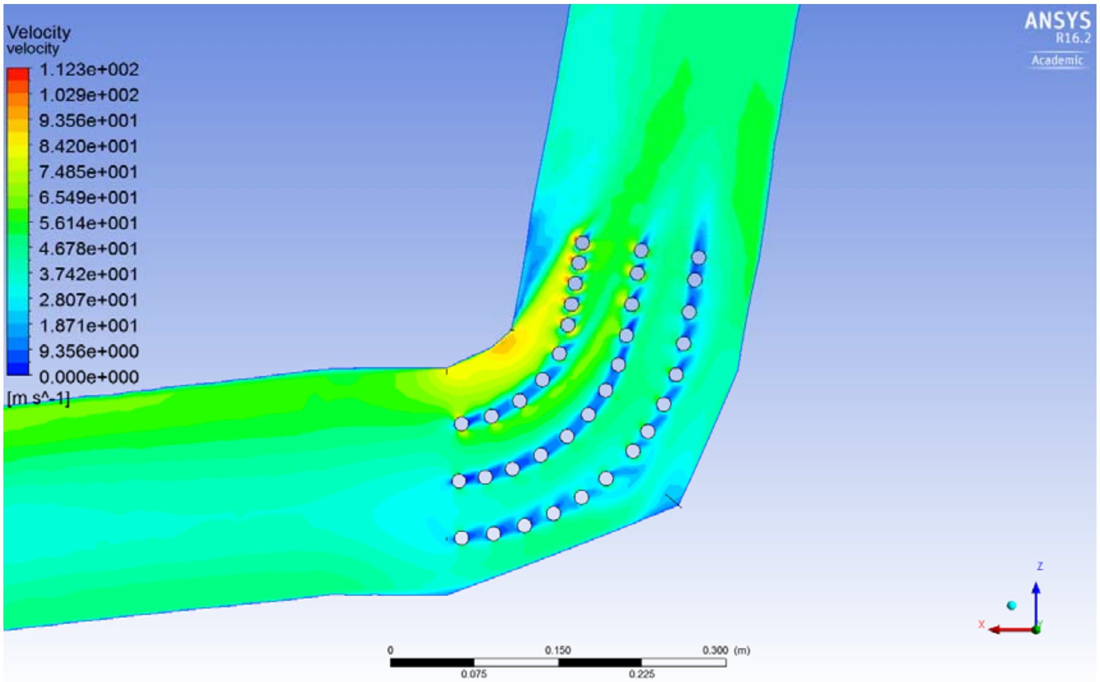

Figure 30. Contour Map of Variable Velocity for the Final Heat Exchanger Design.

The flow field in Figure 30 looks similar to the one in Figure 27 but has some key differences. One of the main differences is the size of the recirculation area just after the bend. The size of the separation zone has been reduced slightly from the same zone before the extra tubes were added. The reason for the change in size of the separation zone is the second main difference: more of the flow from that begins between the top wall of the duct and the top row of tubes remains there. Due to the smaller spacing between the tubes in the upper area, less of the flow from the top stream can leak through into the stream between the top and middle rows of tubes.

Another potential benefit of this change is the possible increase in heat transfer around the tubes with the shortened spacing. The amount of turbulence in the area should cause an increase in the amount of heat transferred to the fluid inside those tubes. Figure 31 shows the streamline view of the flow around the tubes of the heat exchanger.

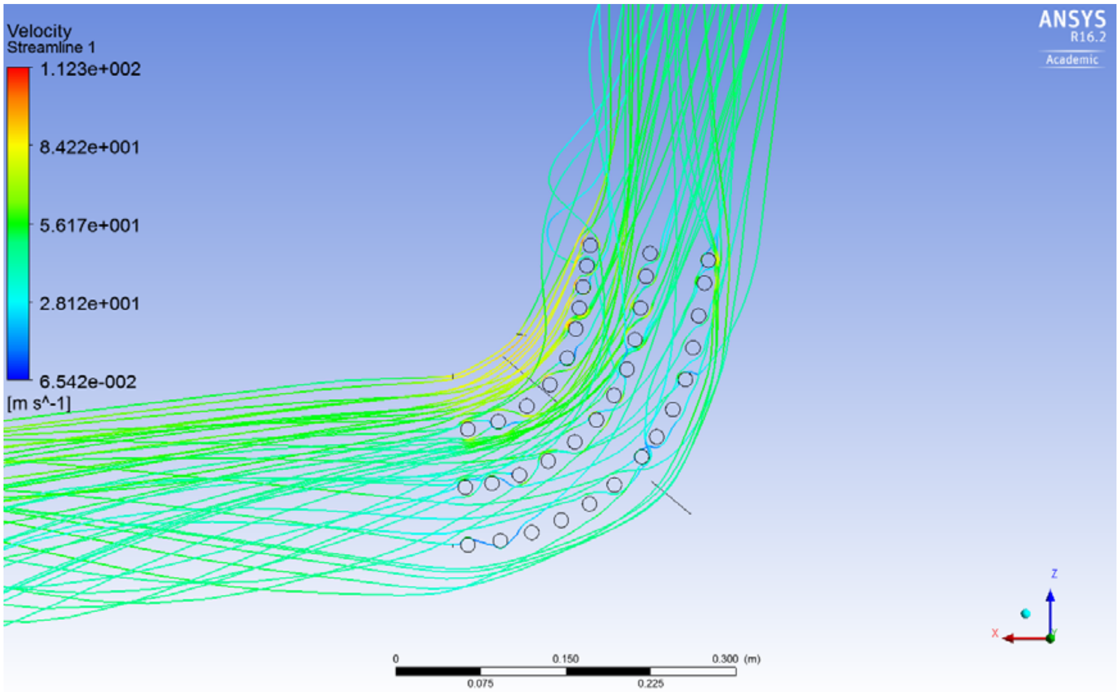

Figure 31. ANSYS Streamline Visualization of Flow Through Tubes of Final Heat Exchanger Design.

The streamlines in Figure 31 do show that some of the flow traverses between the tubes in the upper section of the top row. However, more of the flow appears to follow along the tubes than before the alteration of the tube spacing. The small amount of exhaust gas that flows between the tubes instead of following them will actually tend to increase the amount of heat transferred into the tube and the fluid inside.

The addition of the two extra tubes into the back of the top row of tubes did have an effect on the back-pressure of the exhaust duct. ANSYS estimates that the back-pressure that this heat exchanger design will induce on the engine is 102534Pa (14.87psi). This back-pressure is slightly higher than the baseline value of the unmodified circular exhaust duct; however it is only a 0.2% increase. The engine operation will not be affected by a back-pressure rise of this amount. Therefore, engineering drawings of this heat exchanger design were made for manufacturing and testing of the design. Appendix E shows that drawings that were created.

E. ANALYSIS OF THE HEAT EXCHANGER USING CARBON DIOXIDE AS THE WORKING FLUID

With the design of the heat exchanger finalized, the process of analyzing the actual heat transfer portion of the design began. The decision to use CO_2 as the working fluid of this WHR system stemmed from the fact that this would lead to a more compact setup. ANSYS has built in perfect gas fluid properties for CO_2, so the program needed no modification. In order to set up ANSYS to solve the flow through the tubes, each tube required individual construction in SolidWorks before importing them into ANSYS. The total length of each of the tubes was chosen to be 0.36m (14 inches) long.

In order for the ANSYS CFD solver to run, each of the tubes had to be uploaded as a separate entity. This method of uploading the tubes has one main benefit in the CFD solver: each tube domain and boundary conditions are defined individually. This method also resulted in more control over the specific thermodynamic settings for each of the 36 tubes.

The boundary conditions set for the exit of the heat exchanger tube remained constant through all of the ANSYS solutions. The exit static pressure was assumed to be 0.2MPa (29psi). This value for the exit pressure was also used for the WHR cycle comparison in Chapter V. This similarity between the solution and the WHR cycle comparison allowed for an analysis combining the cycle and the CFD solution.

The process of determining the inlet boundary conditions for the heat exchanger tubes involved an iterative process. The variable parameter for the inlet was the mass flow rate. ANSYS solved the heat transfer through the tubes for each selected mass flow rate. The values of mass flow rate were determined using hand calculations of the Reynolds Number to determine the lowest mass flow rate that would definitely produce turbulent flow in the tubes. Turbulent flow in a convective heat exchange situation produces higher amounts of heat transfer than laminar flow. The Reynolds Number of the fluid flow was determined using Equation 9:

$$\mathrm{Re} = \frac{\rho V D}{\mu}. \tag{9}$$

Assuming a pipe flow Reynolds Number of approximately 5700 to be fully turbulent, the corresponding minimum mass flow rate for the CO_2 tubes equaled approximately 0.001kg/s (0.0022lb/s).

After the solution process, ANSYS returned the outlet temperatures from the heat exchanger tubes. These temperatures were then transferred into an excel database for further analysis using the CO_2 data tables located in Appendix H [18]. The tables provided all of the thermodynamic properties of the gas at the specific temperature and pressure determined by ANSYS. Figure 32 shows the various outlet temperatures from the tubes plotted against the corresponding mass flow rate.

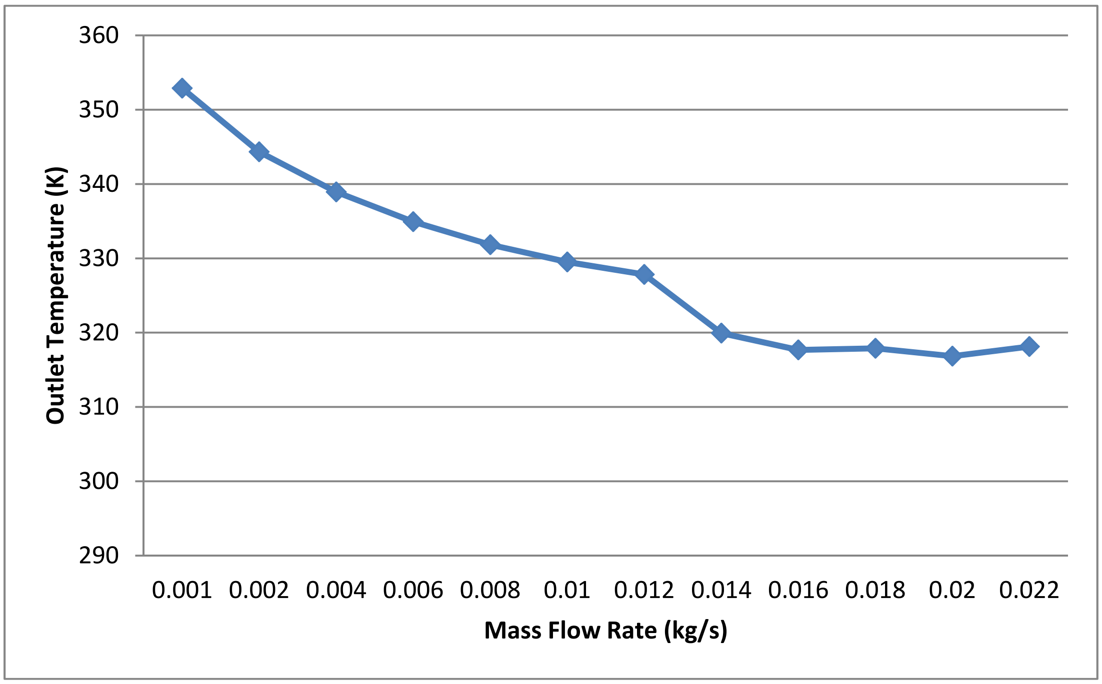

Figure 32. Plot of Tube Outlet Temperatures vs. Tube Mass Flow Rate.

Figure 32 shows that as the flow rate of CO_2 through the tubes increases, the outlet temperature decreases. The temperature decreases until a mass flow rate of approximately 0.014kg/s (0.031lb/s) where the temperature asymptotes to a value of approximately 317K (111°F).

Since Figure 32 does not appear to show a particular mass flow rate that performs better than the others, further analysis of the data was necessary. Using the thermodynamic properties of the gas, it became necessary to determine the amount of heat that the CO_2 could absorb at a particular mass flow rate. The amount of heat was calculated using the enthalpies of the gas at the inlet of the tube and at the exit of the tube. The calculation of this total heat used Equation 10:

$$Q = \dot{m}\left(h_{out} - h_{in}\right). \tag{10}$$

Figure 33 shows the total heat absorbed by the CO_2 in the tubes as a function of the mass flow rate in the tubes.

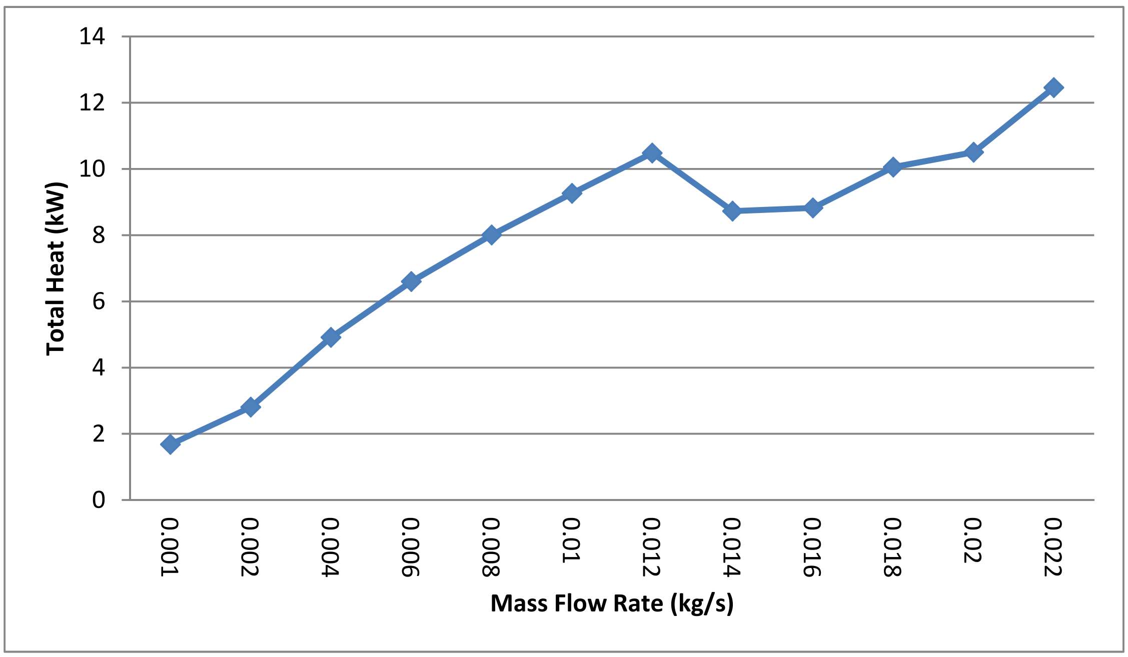

Figure 33. Plot of Absorbed Heat vs. Mass Flow Rate.

The plot in Figure 33 offers more insight into the heat transfer occurring inside the tubes. As the mass flow rate increased from 0.001kg/s to 0.012kg/s (0.0022lb/s to 0.026lb/s), the total heat absorbed by the CO_2 also increased. However, the total heat decreases above a mass flow rate of 0.012kg/s (0.026lb/s) and slowly begins to climb again. The slow climbing of the total heat curve above a mass flow of 0.016kg/s (0.035lb/s) resulted from the asymptotic behavior of the outlet temperature shown in

Figure 32. In order to completely determine the peak mass flow rate for these tubes, the thermal efficiency of the cycle for each mass flow rate was found using Equation 11:

$$\eta = 1 - \frac{T_{Low}}{T_{High}}. \tag{11}$$

The thermal efficiencies solved for were multiplied by the total heat absorbed by the tubes using the respective mass flow rates. This allowed the numbers to reflect total power and the efficiency of the tubes at various mass flow rates. Figure 33 shows these values plotted against the mass flow rates.

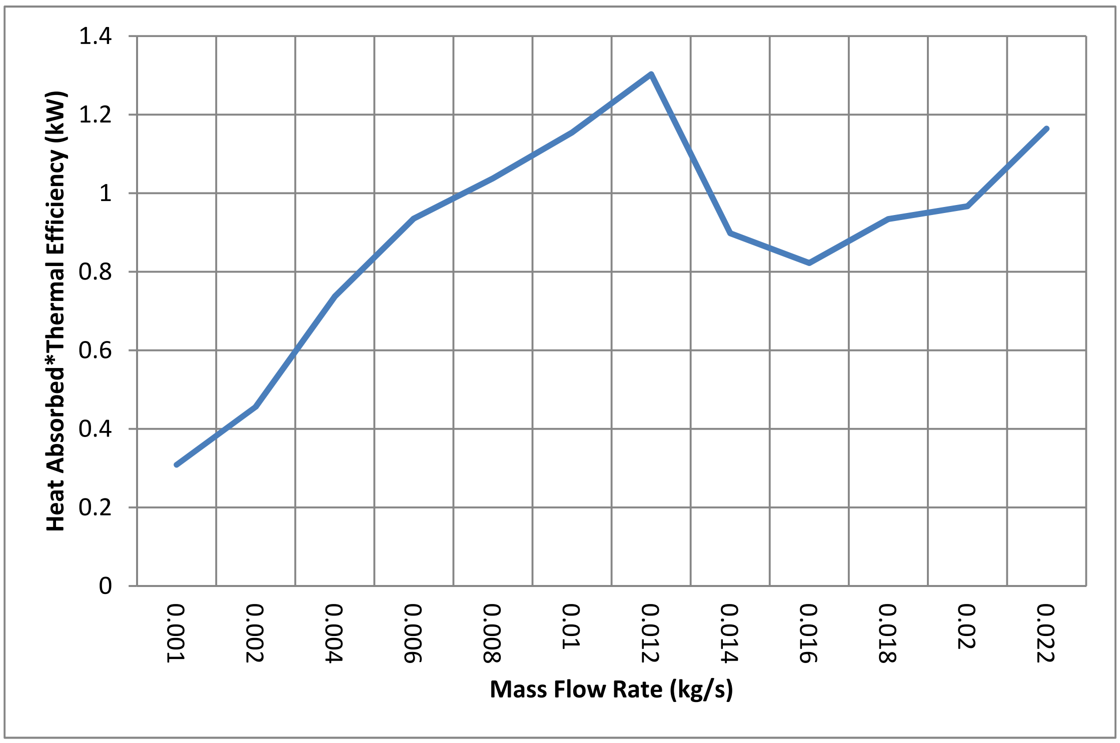

Figure 34. Plot of Efficiency Multiplied by Total Heat Absorbed vs. Mass Flow Rate.

Figure 34 shows that the peak at a mass flow rate of 0.012kg/s (0.026lb/s) became more defined when combined with the efficiency. This result allowed the determination that the mass flow rate in the tubes should be 0.012kg/s (0.026lb/s). Figure 35 shows the ANSYS solution of the heat exchanger with the mass flow rate of CO_2 set to the determined value.

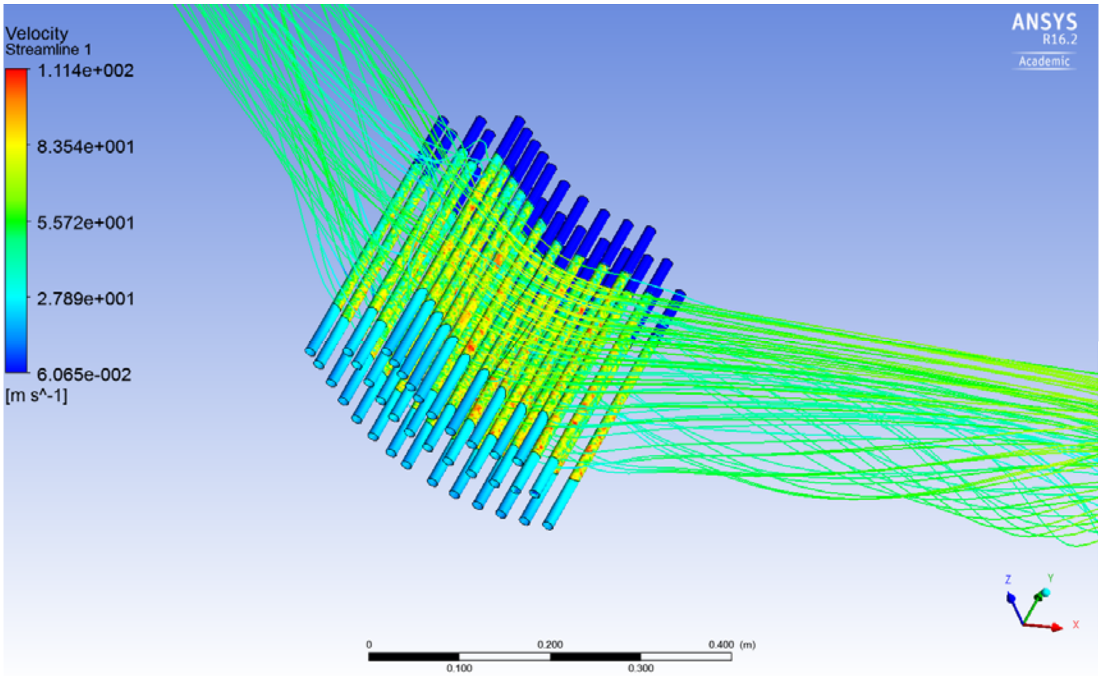

Figure 35. ANSYS Solution of Heat Transfer using 0.012kg/s (0.026lb/s).

Chapter III demonstrated the experimental method used in this thesis to design and analyze the new heat exchanger for the exhaust duct. The results from this analysis show that the heat exchanger design extracts heat from the exhaust while minimalizing the increase of the back-pressure on the engine. This result allowed for the continuation of the research into which WHR cycle to use for this system as well as the analysis of the RankineCycler™.

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IV. BASELINE OPERATION OF THE RANKINECYCLER^{TM}

Chapter III demonstrated the iterative procedure used to design and analyze the new WHR heat exchanger. While working on figuring out the size and design of the heat exchanger for the gas turbine exhaust system, an investigation was initiated for a way to easily acquire the equipment that would be needed to construct the WHR system for the gas turbine. This investigation involved looking for small turbines and generators for the working fluid as well as a condenser and a pump to be able to build the entire WHR system. Turbine Technologies, LTD, which sells an entire, ready to operate, classroom-sized Rankine steam system, was considered. While this system does not include a pump, it does include a turbine, a generator, and a condenser as well as a propane fired boiler.

Operating the system with the boiler would be a good way to compare the results to how it operates using the exhaust gas to heat the fluid. The actual data analysis was also made easier since the RankineCycler^{TM} comes with a laptop which is preloaded with the data acquisition software made especially for this system. This chapter shows the process taken to setup, operate, and analyze the RankineCycler^{TM}. The performance of this system would be used to compare the performance of the WHR system.

A. INITIAL SETUP AND REVIEW OF FACTORY TEST DATA

The RankineCycler^{TM} setup was trivial since the unit was shipped fully assembled. Once removed from the pallet it shipped on, the system was placed in the corner in the marine propulsion lab where it would be operated. The computer was also shipped with the data file acquisition program installed and also contained a file from the factory run of the same RankineCycler^{TM}. The factory data file only contained the raw data from the run as well as a graph of every variable plotted against time. After a quick analysis of the factory data, it was determined that the data acquisition program needed to be calibrated. This conclusion stemmed from the fact that when the data points were plotted on a T-s diagram using the pressures and temperatures from the file, all of the points were located in the liquid water section of the plot.

B. CALIBRATION OF THE DATA ACQUISITION SOFTWARE

The data acquisition software that was provided with the RankineCycler™ has a calibration tab in the program which allows for the user to offset each of the sensors in the system in order to ensure the readings are accurate. According to the data acquisition software, this is done to ensure that the readings stay accurate as sensors may drift in and out of calibration.

1. Stock Calibration

Turbine Technologies, LTD ensured that calibrating the RankineCycler™ was as trivial a process as possible. The stock calibration settings for the RankineCycler™ are shown in Figure 36. The program shows the user what the current reading for each sensor is in the highlighted box. There is also a box that corresponds to each sensor that has up and down arrows for adjusting the offset for the sensor. All of the offsets for the sensors were set to zero with the exception of the boiler pressure sensor which was set to read 20.68KPa (3.00psi) high. The program collected a small amount of data while the system was shut down and had adequate time for cooling to allow the entire system to be in equilibrium with the conditions in the lab. This allowed for the system to be at a known pressure, since it was open to the atmosphere. Also, the temperature readings in the software should match ambient conditions in the lab. The turbine was also not rotating and no current or voltage was being generated while the system was shut down.

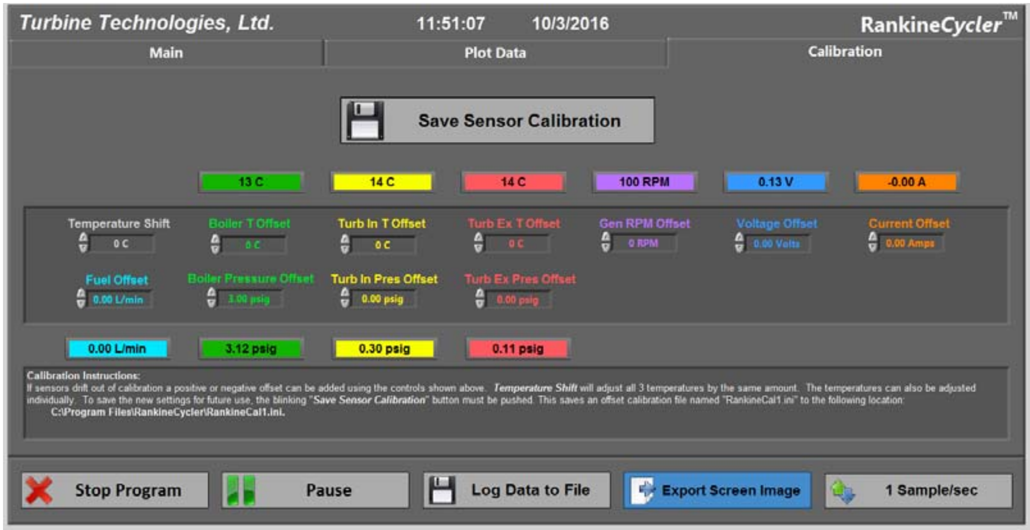

Figure 36. Stock Calibration of the RankineCycler^{TM}.

Using a calibrated K-type thermocouple, the ambient air conditions were measured inside one of the central boiler tubes. Each of the sensors was individually adjusted to ensure that the readings were as accurate as possible to allow for measurement of the steam conditions while operating the system.

2. New Calibration Settings

The calibration of the sensors proved to be a trivial process and was soon completed. Once each of the sensors was adjusted, the readings displayed what the output is known to be. The final calibration settings for the RankineCycler^{TM} are in Figure 37. The thermocouple inside the boiler tube indicated that the temperature inside the system was 20.9°C (69.62°F). Each of the thermocouples in the data acquisition software was adjusted until they read 21°C (69.8°F) ± 1°C. The three pressure sensors inside the RankineCycler^{TM} measure gauge pressure and should have been reading zero when the system was opened to the ambient conditions. All of the pressure sensors were also adjusted individually until they read zero psig ± 0.02psi. The turbine revolutions gauge was calculated using the voltage meter reading [19]. The baseline reading for this always shows the generator rotating at 100 RPM. Therefore, the sensor was adjusted to read 0 RPM while the system was not operating. The voltage and ammeter were adjusted so that they read 0 volts ± 0.02 volts and 0 amps ± 0.01 amps, respectively.

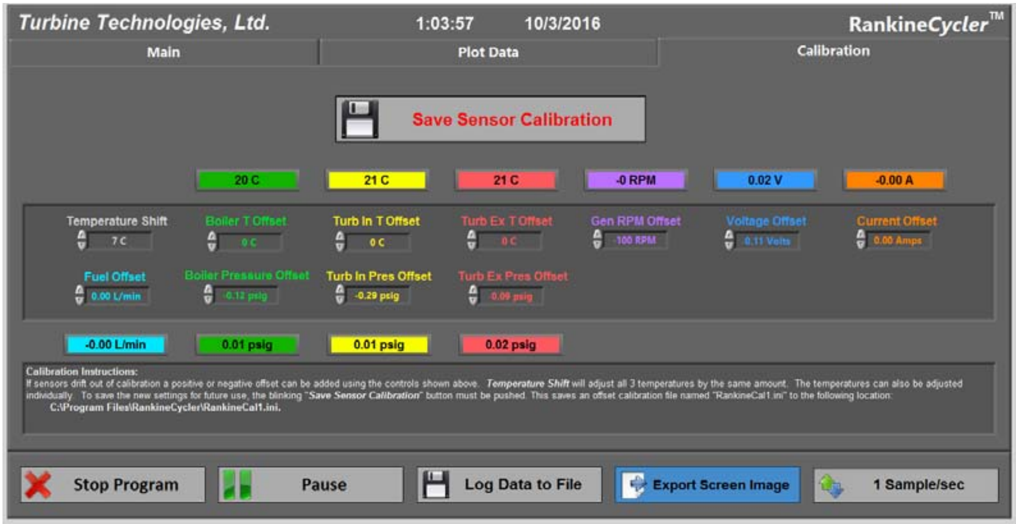

Figure 37. Adjusted Calibration Values for the RankineCycler™.

The displayed values for the sensors now matched what they should be reading for the system to be shut down and in equilibrium. The factory supplied data was modified by adding the offset values to the data in order to account for the new calibration settings. This simple solution brought the points on the T-s diagram into the superheated steam region, where they should have been.

C. DATA COLLECTION RUNS

Once the RankineCycler™ was set up and ready for use, the system was run in order to verify the factory run data, ensure the system operated properly, and to determine if the operating instructions in the Operator's Manual were simple and easy to follow.

1. Operation of the RankineCycler™

The setup of the RankineCycler™ system prior to lighting off the boiler was easy to do and consisted of several visual checks of the main equipment such as the boiler, turbine, switches, and condenser. The Operator's Manual contained the normal operating instructions for system startup and shut down [19]. The condenser and boiler were fully drained of water prior to filling the boiler with distilled water in order to be able to know the exact amount of water in the system.

The operating manual allowed the startup of the RankineCycler^{TM} to be a quick process. Figure 38 shows the supplied beaker on top of the condenser where it is positioned when filling the boiler with distilled water. The boiler is filled with a maximum of 5500ml (186 fluid oz). The throttle valve should be opened in order to vent the air inside the system while filling the boiler. Once the boiler has been filled, the throttle valve was closed, the fuel valves were opened, and the boiler was lit off. The system purged for approximately 45 seconds before the boiler attempted to light. For each time that the system was operated, the boiler failed to light properly the first time. In this event, the boiler switch was turned off and then back on to allow the system to purge a second time. This second purge worked properly in each of the runs and allowed the boiler to ignite without any further issue. The procedure for a failed light off is also in the Operator's Manual [19].

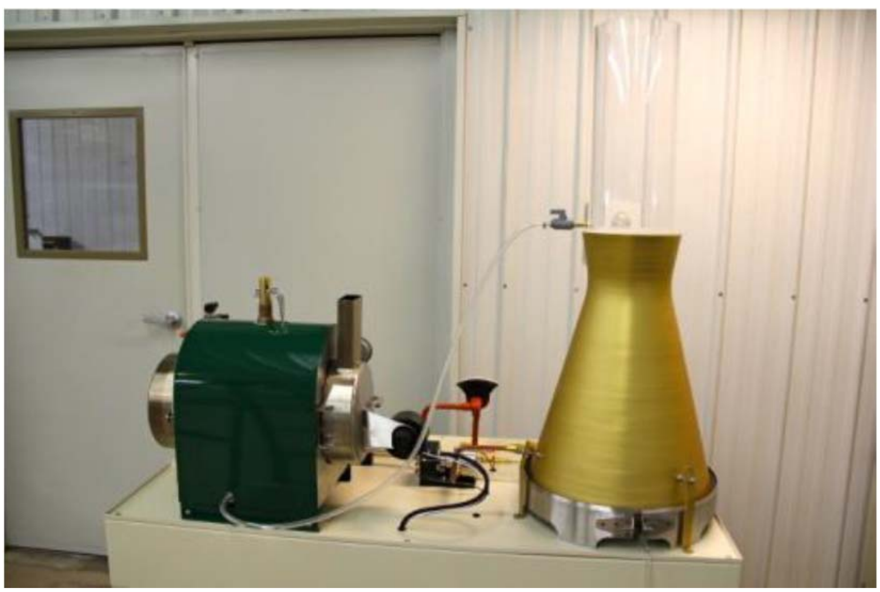

Figure 38. RankineCycler^{TM} System Showing Beaker for Filling Boiler. Source: [18].

Operation of the data acquisition program proved to be trivial. The data acquisition program began to log the data after a filename is chosen in the program. This program, along with the pressure gauge shown in Figure 39, allowed the user to be able to monitor the rising boiler pressure and temperature.

The boiler pressure continued to rise until it reached approximately 827KPa (120psig). At this pressure, the throttle valve was slowly opened to send steam through the turbine and condenser. During this venting process, the turbine speed was monitored carefully using the voltage meter on the RankineCycler™. In accordance with the operating manual, the voltage produced during this process should not exceed 9 volts [19]. The readings were not constant and changed rapidly as slugs of water would pass through the turbine during this phase of the operation. The steam was allowed to vent through the system until the boiler pressure dropped to below 345KPa (50psig). At this pressure, the throttle valve was closed and the pressure began to rise again.

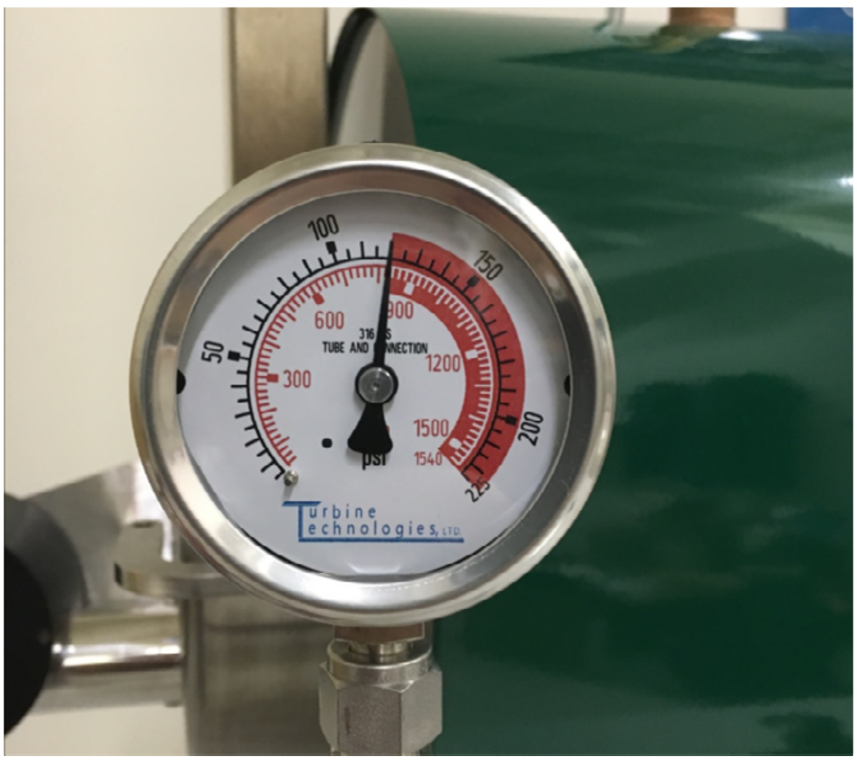

Figure 39. RankineCycler™ Installed Pressure Gauge for Monitoring Boiler Pressure.

Once the boiler pressure reached 827KPa (120psig), the throttle valve could be opened slowly to allow steam to pass through the turbine. The voltmeter was closely monitored so that it did not exceed 9 volts during this process. Once the turbine was rotating at about 2500 RPM, the generator began producing approximately 9 volts and 3 amps. With the boiler pressure maintained near 827KPa (120psig), this was the steady state operating condition of the RankineCycler^{TM}. The system continued operating at these conditions for approximately 18 minutes.

Once the boiler shut off, the throttle valve was opened slowly in order to vent all of the pressure in the boiler while the turbine speed was monitored. This allowed the boiler to cool faster and puts the system into a known safe condition. The Operator's Manual provided instructions on how to fully secure and drain the system [19]. A good rule of thumb that was determined is to allow at least 2 hours for cooling of the system prior to draining the water from the boiler and the condenser.

2. Analysis of System Operation and Data Collection

The purpose of the operating the system for the trial runs was to collect data and complete a full analysis of the system. The data that was collected provided more insight into the operation of the system than the user manual gave. The data acquisition software collected five data points per second throughout the operation of the RankineCycler^{TM}. This short period allowed for every change in the system to be logged for further analysis. The data from these runs allowed for the performance of a full analysis on the system. The completed analysis would be used to compare the performance of the WHR heat exchanger while operating using a different thermodynamic cycle.

During operation of the RankineCycler^{TM}, two of the safety mechanisms were tested to ensure operation. One of the safeties checked was the turbine over speed indicator. The alarm is not easily seen and does not have any audible noise associated with it. The only indication that the turbine is rotating too quickly is on the data acquisition program; the gauge where the RPM is displayed will turn bright red.

The other safety checked during the operation was the boiler low water level alarm. This alarm also has no audible sound associated with it. However, this alarm will secure the burner and shut down the boiler to prevent any damage from overheating a boiler with no water in it. This alarm will trigger when there is approximately 1600ml (54.1 fluid oz) of water remaining in the boiler.

D. FULL ANALYSIS OF DATA ACQUIRED FROM TRIAL RUNS

The data collected from the operation of the RankineCycler™ required some work before the data could be fully analyzed. Table 4 shows sample data from the first trial run of the RankineCycler™. The table also includes both the entropy and enthalpy, obtained from NIST, of the steam at each of the three main points; the boiler, the turbine inlet, and the turbine outlet [18]. The full data tables for all of the operating runs and the factory run are located in Appendix F.

Table 4. Sample Data Table for Operating Run 1.

Variable	Average value
Boiler Temperature	187.8 °C (369.78 °F)
Turbine Inlet Temperature	123.69 °C (254.38 °F)
Turbine Exit Temperature	110.85 °C (231.26 °F)
Boiler Pressure	876.32 KPa (127.1 psia)
Turbine Inlet Pressure	180.85 KPa (26.23 psia)
Turbine Exit Pressure	120.93 KPa (17.54 psia)
Boiler Entropy[a]	6.7052 KJ/Kg*K (1.6026 Btu/lbm*R)
Turbine Inlet Entropy[a]	7.1958 KJ/Kg*K (1.7198 Btu/lbm*R)
Turbine Exit Entropy[a]	7.3263 KJ/Kg*K (1.7510 Btu/lbm*R)
Boiler Enthalpy[a]	2805.9 KJ/Kg (1207.1 Btu/lbm)
Turbine Inlet Enthalpy[a]	2715.5 KJ/Kg (1168.2 Btu/lbm)
Turbine Exit Enthalpy[a]	2695.3 KJ/Kg (1159.5 Btu/lbm)

[a]Entropy and Enthalpy data obtained using NIST [18].

Using the temperatures and entropies for the three data points for each run, a Temperature Entropy (T-s) diagram was created using MATLAB® in order to view the throttle valve and the turbine thermodynamically. Figure 40 shows the T-s diagram of the operational runs. The thermodynamic cycles from the data are different from most in that there are only three known points in this system. Therefore, the only two pieces of equipment that could be fully analyzed are the turbine and the throttle valve. Also, in most steam systems, the turbine is the main piece of equipment that takes energy from the steam and turns it into usable work for an end process. In this system, the throttle absorbed most of the energy from the steam since the pressure drop across the throttle was substantial.

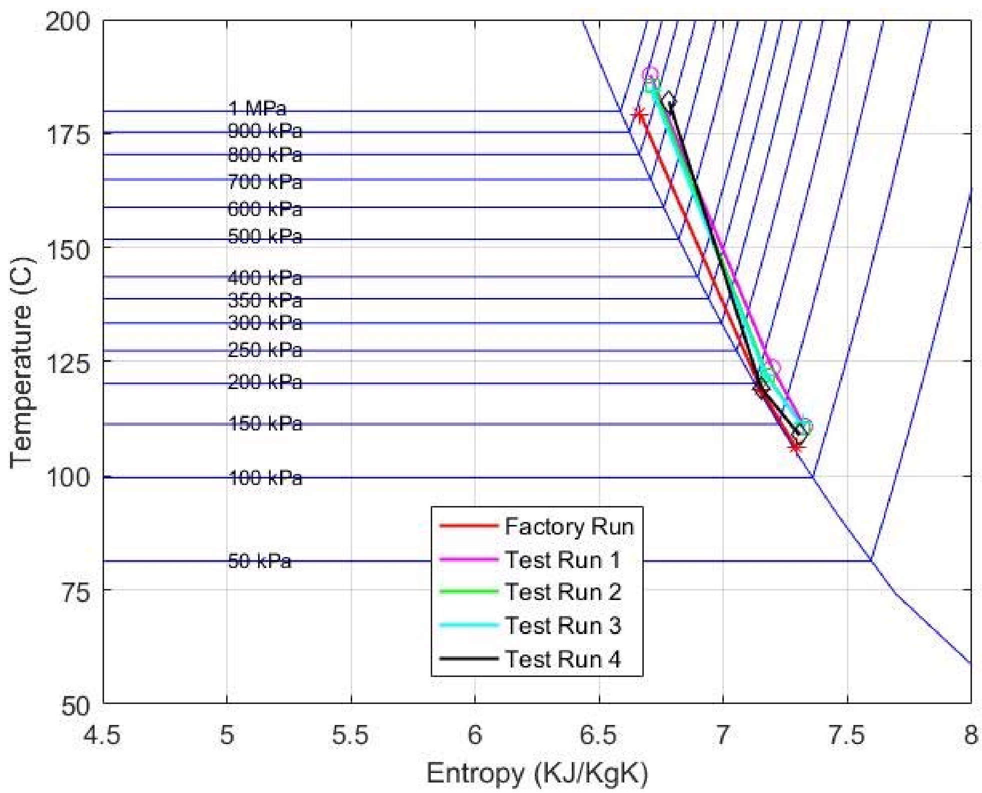

Figure 40. Temperature-Entropy Diagram for Water with Factory Data and Data from Operating Runs 1-4. Adapted from [18].

The multiple lines shown in Figure 40 are the associated drops in temperature and increases in entropy associated with the throttle valve and the turbine of the RankineCycler™ for each of the runs. Using the values of the enthalpies for the inlet and exit of turbine allowed calculation of the overall efficiency of the turbine using Equation 9.

$$\eta = \frac{h_{in} - h_{out}}{h_{in} - h_{out,ideal}} \tag{9}$$

Since Table 4 shows h_{in} and h_{out}, the only enthalpy that remained was $h_{out,ideal}$, which would be the enthalpy at the exit of an ideal turbine. This enthalpy can be found while assuming the turbine is isentropic, which means the entropy of the steam would not increase through the turbine. Thus, to find the ideal exit enthalpy, a straight line is drawn down from the turbine inlet location on the T-s diagram in Figure 40 until this vertical line intersects the isobar line for the turbine exit pressure. This position is under the dome of the diagram, and results in a mixture of vapor and liquid water. Using Equation 10, the quality of the steam can be found. The quality is defined as the ratio of the mass of vapor to the total mass of the liquid [20].

$$s = s_f + x \times s_{fg} \,. \tag{10}$$

Rearranging to solve for the quality x results in

$$x = \frac{s - s_f}{s_{fg}} \,, \tag{11}$$

where s is the known entropy at the turbine inlet, s_f is the entropy of the liquid, and s_{fg} is the value obtained when the entropy of the liquid is subtracted from the entropy of the vapor. Using Equation 11, the quality of the steam at the ideal turbine exit is 98%, meaning that 98% of the liquid vapor mixture by mass is vapor. This value is then used in Equation 12 in order to find the ideal exit enthalpy of the turbine:

$$h = h_f + x \times h_{fg} \,. \tag{12}$$

The ideal exit enthalpy for this turbine is 2645.7kJ/kg (1137.46BTU/lbm). Going back and using Equation 9 yields a thermodynamic efficiency of the turbine of 28.9%. Most large multistage turbines have efficiencies in the high 90% range, so this efficiency is very low, even for a single stage impulse turbine.

The knowledge gained by analyzing this Rankine cycle allows for a more complete analysis and comparison of the WHR cycles shown in Chapter V. When the WHR heat exchanger is built and installed in the exhaust duct of the Allison 250 gas turbine engine, the RankineCycler^{TM} analysis can be compared to the performance of the WHR cycle.

V. COMPARATIVE ANALYSIS OF RANKINE AND BRAYTON CYCLES FOR WHR

The work in Chapter IV analyzed a Rankine cycle for the purpose of comparing the performance of the cycle to the WHR device that will be designed for the exhaust duct of the Allison 250 gas turbine engine. However, the new heat exchanger design will be based around using CO_2 as the working fluid instead of distilled water. This new use for CO_2 is slowly becoming more prominent in WHR device designs. However, CO_2 must be maintained at high pressure to exist in a liquid state. This high pressure increases the complexity of the design and the system in order to prevent any sort of leak that can cause injury. Chapter V presents a full comparative analysis of three different WHR cycles that being considered for use in the designed heat exchanger. The analysis was completed using exhaust data from an LM2500 gas turbine engine after a brief literature review into previous cycle comparisons.

A. WHR CO_2 CYCLE COMPARISON LITERATURE

In 1985, the National Aeronautics and Space Administration (NASA) in collaboration with the U.S. Department of Energy (DOE) conducted research comparing steam Rankine cycles, organic Rankine cycles, and Brayton cycles for WHR [21]. The comparisons were based on the exhaust data from a diesel engine for a truck. The purpose of the research was to determine if using WHR devices in road trucks would help reduce emissions and be cost effective [21]. The report concluded that the steam and organic Rankine cycles were more effective than the Brayton cycle for the purposes of reducing the specific fuel consumption of the diesel engine [21]. However, the report also concluded that with the cost of diesel fuel at the time, no waste heat recovery device would be able to pay for itself and therefore making the changes was not economical [21].

The US government was not the only entity looking into comparing different cycles for WHR in the 1980s. Civilian research companies looked into WHR in order to cut operating costs of machinery in manufacturing and power generation plants. One in particular compared Rankine and Brayton WHR cycles for use in a glass melting plant to extract the heat from the furnace [22]. They found that the organic Rankine cycle using toluene produced the most power for the exhaust flow [22]. They also found that the only cycle that was not worth considering was a sub-atmospheric pressure Brayton cycle since that was the only cycle that was not cost effective [22].

While these papers both looked into Brayton and organic Rankine cycles, neither of the teams used CO_2 as the working fluid. A report from the 2015 Gas Turbine Congress in Tokyo shows the research by a team looking into a supercritical CO_2 WHR system [23]. This paper compared the performance of different combinations of CO_2 supercritical cycles to determine the most effective system [23]. They found that a composite cycle which uses multiple sequentially installed supercritical CO_2 systems was the most effective in terms of amount of installed equipment and system performance [23]. The US DOE also looked into supercritical CO_2 cycles in 2015 and published a report at the Quadrennial Technology Review [24]. In addition to recommending that more funds be spent on research and development for the technology of a supercritical CO_2 cycle, the DOE report compared using CO_2 as the working fluid with nitrogen and helium [24]. They found that the highest cycle efficiency possible was attained while using CO_2 instead of nitrogen or helium [24]. These few examples of research into using CO_2 as the new working fluid for WHR compare different types of the same cycle to determine the most effective solution.

B. COMPARISON OF RANKINE, TRANSCRITICAL AND BRAYTON CYCLES USING CO_2 AS THE WORKING FLUID

Since most of the larger ships in the US Navy use LM2500 gas turbine engines, the comparison between the cycles will be made using the exhaust values for the LM2500. Using the same exhaust flow at the same temperature allows fewer variables when comparing the performance of the three systems. Table 5 shows the values for the exhaust flow used in this analysis.

Table 5. LM2500 Parameters for WHR Cycle Comparison and Analysis. Source: [3].

Parameter	Value
Exhaust gas mass flow rate	70.5 kg/sec (155.43 lb/sec)
Exhaust Temperature In	839K (1050.5°F)
Assumed Exhaust Temperature Out	800K (980.3°F)
Average Specific Heat (C_p)[a]	1.0715 kJ/kg*K (0.263 BTU/lbm*°F)
Heat Rate	2946.1 kW (167542 BTU/min)
Power Produced	25060 kW (33600 SHp)

[a]Values for specific heat taken from [20].

Some simplifying assumptions were made about the exhaust flow and the WHR heat exchanger. The first simplifying assumption that was made was the exhaust gas outlet temperature from the heat exchanger. The outlet temperature of the LM2500 exhaust was assumed to be 800K (980.3°F). This allowed the amount of heat extracted to be calculated using Equation 13:

$$Q = \dot{m} C_p \Delta T \ . \tag{13}$$

Table 5 contains the heat rate calculated from Equation 13 as 2946.1kW (167452BTU/min). The second simplifying assumption made for this analysis was that all of the heat that exits the exhaust gas is transferred to the CO_2 inside the heat exchanger. This assumption simplifies the calculations by assuming the design of the heat exchanger is perfect and does not hinder the heat transfer process in any way.

One other main simplifying assumption was made about each of the three cycles being analyzed. This assumption involved the compressor or pump and turbine of each cycle. The analysis assumed these devices to be isentropic. This assumption simplifies the calculations of the power needed or created by the compressor or pump and turbine by setting the isentropic efficiency to one.

One other assumption made for the different WHR cycles is that the pump or compressor pressure ratio is always 2:1. This allows for simple comparison of the pumping or compressing power required in each case to get from the base pressure up to twice the value of the base pressure.

Two of the cycles analyzed involved recuperation as part of the cycle. The recuperating heat exchanger was assumed to be perfectly ideal, such that all of the heat from the hot stream is transferred into the cold stream. This assumption basically negates the need for a condenser in the cycle. This is a very crude assumption. However, since the assumption involved both cycles, the comparison between the cycles remains valid.

1. Analysis of WHR Using a Rankine Cycle

The Rankine cycle is a basic cycle more commonly known as a steam cycle. In most cases, the Rankine cycle is operated using water as the working fluid. The cycle can be operated using many different fluids other than water. In this analysis, the Rankine cycle will be operated using CO_2 as the working fluid. The first assumption for this cycle was to have the cycle operate between 2MPa and 4MPa (291.1psi to 580.2psi). Figure 41 shows the T-s diagram for CO_2 with this Rankine cycle plotted.

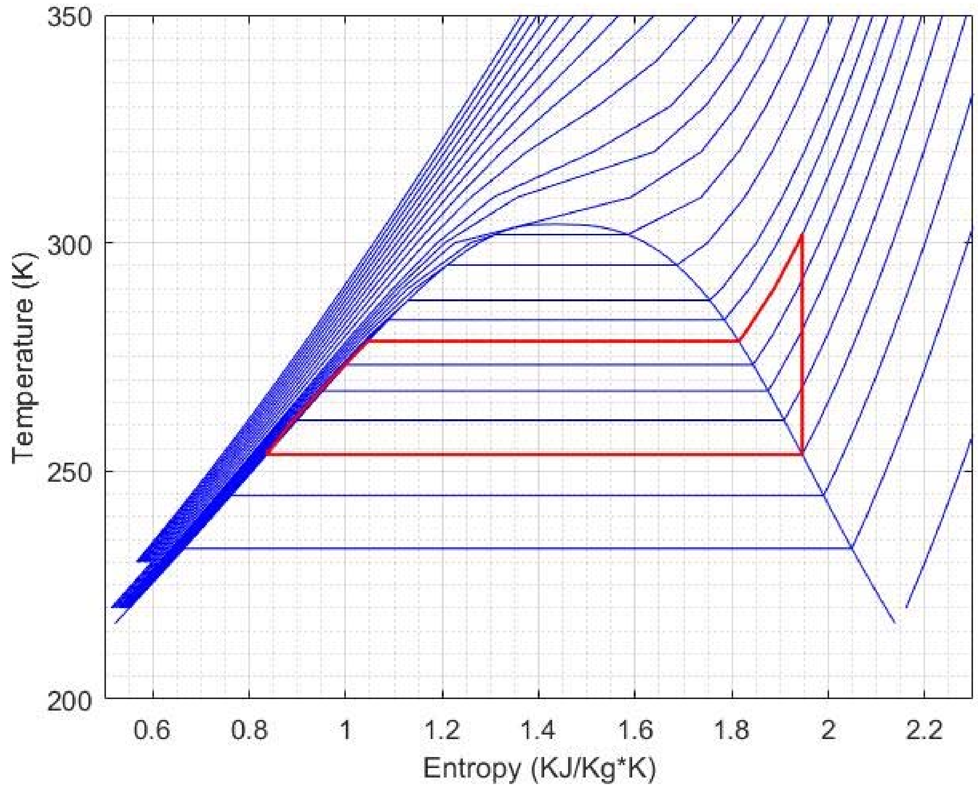

Figure 41. T-S Diagram for CO_2 with 2-4 MPa Rankine Cycle Plotted. Adapted from [18].

The cycle highlighted in red shows a typical Rankine cycle with an isentropic pump and turbine. Table 6 contains the main calculated values for this cycle. Appendix G tabulates all of the calculated values for this cycle.

Table 6. Calculated Rankine Cycle Parameters Using LM2500 Heat Rate.

Parameter	Value
Mass flow of CO_2	9.57 kg/sec (21.1 lb/sec)
Turbine Power Out	272.6 kW
Pump Power In	19.6 kW
Total power Out	253 kW
Efficiency	8.59%

The data shown in Table 6 demonstrates that the Rankine cycle can produce a total of 253kW of power. However, the cycle efficiency is only 8.59%, which is far from ideal. One other main drawback to this cycle is the temperature inside the condenser. In order to get this cycle to operate at all, the CO_2 would have to be cooled to 253.65K (-3.1°F). The only way to ensure that the CO_2 is always cooled to that temperature would be to use a refrigeration cycle to remove the heat.

A bottoming cycle was solved using refrigerant R-134a as the working fluid to see how much power it would take to cool that amount of CO_2 to 253.68K (-3.1°F). The bottoming refrigeration cycle would use 857.2kW of power to operate. Therefore, the Rankine cycle in this configuration would use 604.2kW more than it would produce.

2. Analysis of WHR Using a Transcritical Rankine Cycle with Recuperation

The second cycle that was analyzed for WHR use was the transcritical Rankine cycle. The main difference between this cycle and a standard Rankine cycle is that the high pressure side of this cycle is above the dome of the T-s diagram and is thus a supercritical fluid. The pressure difference for the analysis of this cycle was between 6MPa and 12MPa (870.2psi to 1740.5psi). Figure 42 shows the T-s diagram for the transcritical Rankine cycle.

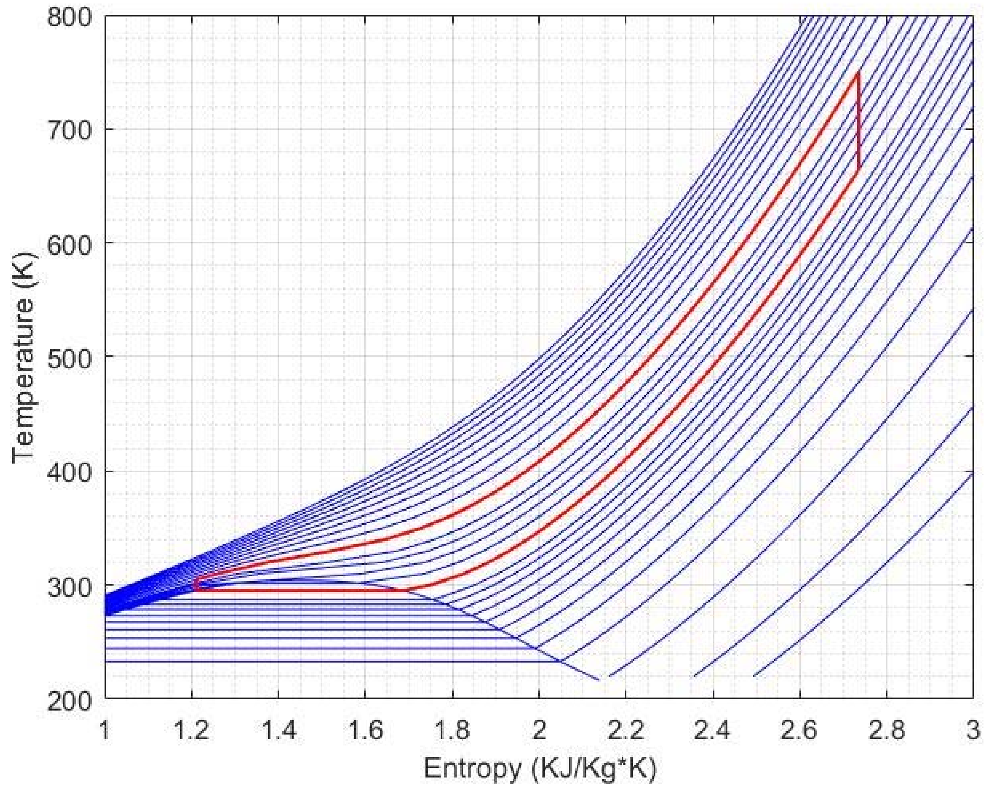

Figure 42. T-S Diagram for CO_2 with 6-12 MPa Transcritical Rankine Cycle Plotted. Adapted from [18].

Figure 42 shows that this cycle's high pressure side is above the dome and is therefore a supercritical fluid. This cycle is also shown with recuperation. Placing a recuperator in the cycle greatly improves the efficiency of the system by using the leftover heat from the hot stream exiting the turbine to preheat the cold stream of fluid prior to entering the boiler. This prevents this heat from going to waste and allows the system to produce more energy. Table 7 shows the main calculated values for this cycle. Appendix G contains all of the calculated values for this cycle.

Table 7. Calculated Transcritical Rankine Cycle Parameters Using LM2500 Heat Rate.

Parameter	Value
Mass flow of CO_2	19.1 kg/sec (42.1 lb/sec)
Turbine Power Out	1772.4 kW
Pump Power In	149.9 kW
Total power Out	1622.5 kW
Efficiency	55.1%

The data in Table 7 show that this cycle can produce 1622.5kW of power with the exhaust heat from the LM2500. This is more than a 600% increase compared to the power produced by the standard Rankine cycle. This cycle also operates at a thermodynamic efficiency of 55%, which is considered to be on the high end of efficiencies for WHR systems. This cycle produces approximately 6.5% of the power produced by the LM2500 gas turbine. While this value does not seem like much, the power produced would otherwise have been lost up the exhaust stack.

This cycle also has one other positive feature when compared to the standard Rankine cycle. The low temperature in this cycle is at 304.8K (89°F). This temperature is more reasonable for being able to cool the CO_2 without having to resort to using a refrigeration bottoming cycle.

3. Analysis of WHR Using a Brayton Cycle with Recuperation

The final cycle analyzed was the Brayton cycle. This cycle does not have a liquid portion, only vapor, so the pumps in the previous cycles are compared with a compressor in this cycle. However, other than the name of the component, everything else remains the same. The pressure ratio for this system's analysis was 0.1MPa to 0.2MPa (14.7psi to 29.4psi). This cycle contained the same recuperation as the Transcritical Rankine cycle had for comparison. Figure 43 shows the T-s diagram for this Brayton cycle.

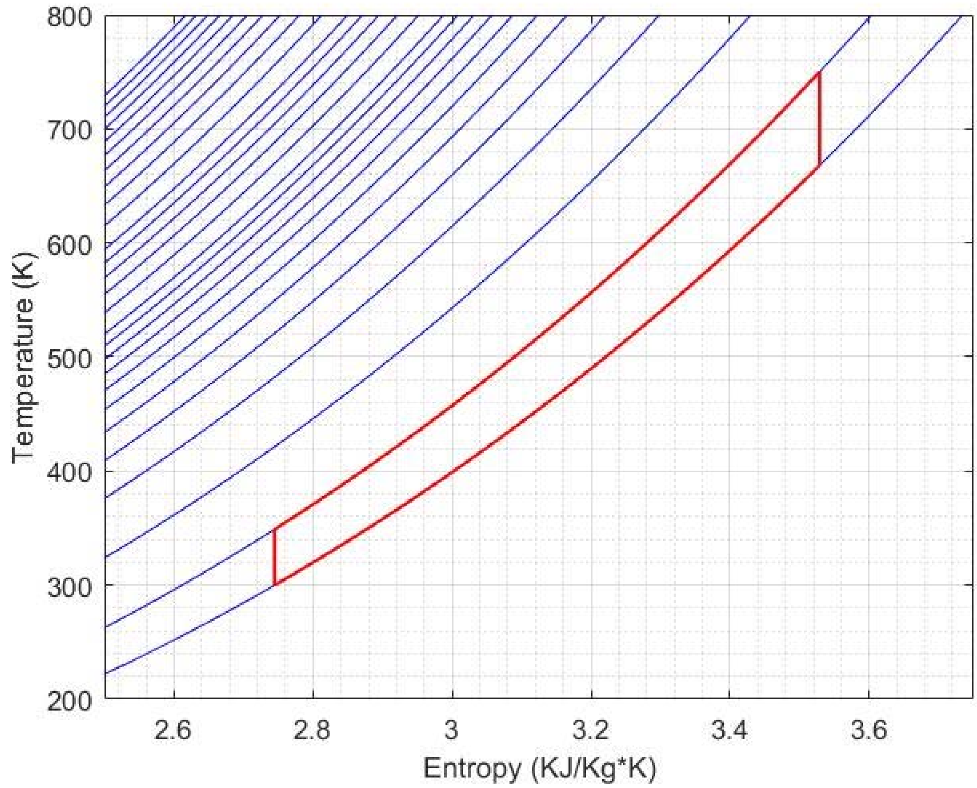

Figure 43. T-S Diagram for CO_2 with 0.1-0.2 MPa Brayton Cycle Plotted. Adapted from [18].

The Brayton cycle had one other assumption that the other two cycles did not: the lower temperature limit. In the Brayton cycle, since the working fluid is constantly in a vaporous state, the lower limit for cooling can vary depending on how it is being cooled. For this analysis of the system and comparison with the other two cycles, the lower temperature limit was assumed to be 300K (80.3°F). Table 8 shows the main calculated values for this Brayton cycle. Appendix G tabulates all of the calculated data for this system.

Table 8. Calculated Brayton Cycle Parameters Using LM2500 Heat Rate.

Parameter	Value
Mass flow of CO_2	26.1 kg/sec (57.5 lb/sec)
Turbine Power Out	2424.9 kW
Pump Power In	1103.4 kW
Total power Out	1321.5 kW
Efficiency	44.9%

Table 8 shows that this Brayton cycle is capable of producing 1321.5kW of power with a cycle efficiency of 44.9%. This shows that the total power output and the cycle efficiency are comparable to the transcritical Rankine cycle. However, the high pressure side of the Brayton cycle is an 88% reduction compared to the high pressure side of the transcritical Rankine cycle. This cycle produces approximately 5.3% of the power produced by the LM2500 engine. This percentage is slightly lower than for the transcritical Rankine cycle.

VI. SUMMARY AND CONCLUSION

Chapter V showed the full analysis and comparison of three different WHR cycles to determine which cycle should be used for the new WHR design in Chapter III. This Chapter will present the findings and conclusions of this thesis.

A. SUMMARY

1. Heat Exchanger Design

The research in the area of heat exchanger design enclosed several new innovative ideas. The first result showed that changing the duct geometry from a circular cross-section to an ovular cross-section drastically reduced the size of the separation zone caused by the sharp corner in the bend. This reduction in the separation area also allowed the exhaust to flow more freely through the duct which lowered the back-pressure on the engine. In fact, this simple geometry change reduced the back-pressure by 20%, dropping from 102317Pa (14.84psi) to 102165Pa (14.82psi). The second result stemmed from designing a new layout for a heat exchanger that extracts heat while minimizing the back-pressure increase on the engine. Chapter III shows the final design of the 36 tube heat exchange. A CFD analysis of the exhaust duct with the heat exchanger tubes in place showed that the tubes did behave like turning vanes, as designed. This turning assisted the flow of the exhaust through the bend, which also prevented an increase in back-pressure. The ovular cross-section successfully accounted for the reduction in flow area due to the tubes being added. This result prevented a restriction in the exhaust duct at the beginning of the heat exchanger which would have increased the back-pressure. The final design was estimated to have a back-pressure on the engine of 102534Pa (14.87psi). In total, the back-pressure on the engine was increased by approximately 20% above the baseline values. However, when comparing the back-pressures in absolute terms, the rise was only 217Pa (0.03psi). This minute rise in the back-pressure would not cause any effect on the engine and was therefore deemed acceptable.

The optimal mass flow rate of CO_2 was determined iteratively to be 0.012kg/s (0.026lb/s). This is the recommended flow rate for the cooling gas. This mass flow rate only achieved a temperature increase of approximately 30K (54°F). In order to obtain a higher temperature rise in the heat exchanger, the ovular cross-section and tube layout should be continued through the vertical section of the exhaust duct.

2. WHR Cycle Comparison

Chapter V shows the comparison of the three WHR cycles analyzed. This analysis showed that while using CO_2 as the working fluid of a WHR cycle, the traditional Rankine cycle is highly ineffective. This stems from the fact that the condenser would have to cool the CO_2 at temperatures well below room temperature. When this cycle was analyzed with an R-134a bottoming cycle, the results showed that the bottoming cycle consumed approximately 10 times more power than the Rankine cycle produced. The Rankine cycle was not considered for this WHR design due to those facts.

The transcritical cycle, also shown in Chapter V, is a more complex system than the Rankine. This system involved using high pressure to have the boiler heat a supercritical fluid. The supercritical fluid was heated to an assumed 750K (890.3°F). This temperature rise allowed this cycle to produce 1622.5kW, which equated to approximately 6.5% of the power produced by the LM2500. This large amount of power output appeared to be an attractive option for the WHR system. However, the high pressure side of the system was assumed to be 12MPa (1740. psi). Research into pipe sizing revealed that any pipe that could handle 750K (890.3°F) and 12MPa (1740.5psi) would need to be specially ordered. Specially ordering the tubes for the heat exchanger would be costly, and as such, this WHR cycle was also not chosen.

The Brayton cycle was the final cycle analyzed in Chapter V. This cycle was assumed to operate between one and two atmospheres of pressure. The lower operating pressures resulted in readily available tubing that could be used for this WHR cycle. The total output power of this cycle was found to be 1321.5kW. While this power was 19% lower than the transcritical cycle, the operating pressure was 88% lower. The Brayton Cycle was selected for this WHR design for these reasons.

B. CONCLUSION

The goals of this research outlined in Chapter I seemed simple, however they involved new ideas and innovative designs. These goals have been met in this thesis and a strong baseline has been laid for future work.

One of the main goals for future work will be to modify the existing heat exchanger design to continue the heat exchanger through the vertical section of the exhaust duct. This change would allow for more flow control of the exhaust and more heat transfer into the CO_2. The heat exchanger should also be built and fully tested to determine the accuracy of the ANSYS estimates.

All in all, this work for the ESTEP program showed that new system designs will allow USN ships to install WHR units once more. This supports the SECNAV's energy goals for the future of the Navy, specifically sailing the Great Green Fleet. The Navy ships of the future will prove to much more energy efficient than today's fleet.

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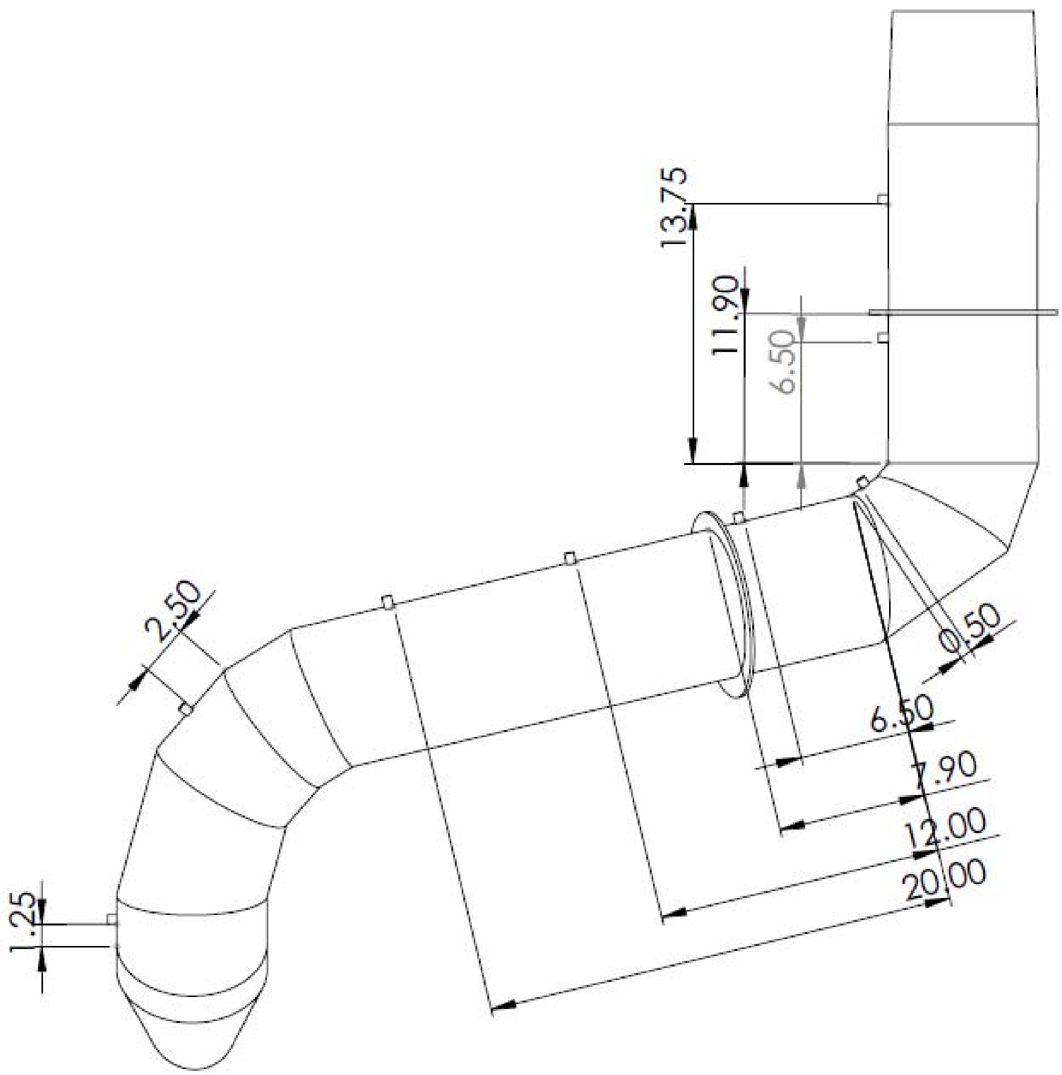
APPENDIX A. SOLIDWORKS DRAWING OF EXHAUST DUCT CUTS AND SENSOR PLACEMENT



All units are in inches.

Figure 44. Drawing of Exhaust Duct Cuts and Sensor Locations.

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APPENDIX B. RAW ENGINE DATA BEFORE OVERHAUL

Note: The values in columns 1–3 in each of the tables in this Appendix are the rotational speeds of the engine. N1 is the compressor speed, N2 is the power turbine speed and N3 is the dynamometer speed.

Table 9. Engine Operating Temperatures in Degrees Celsius.

N1	N2	N3	T2 Inlet	T3 Outlet	T4	T5	T7
RPM	RPM	RPM	Celsius	Celsius	Celsius	Celsius	Celsius
43440	20941	3600	21.267	205.467	966.553	655.332	366.452
43400	24467	4200	22.706	206.330	953.385	646.698	372.198
43460	27873	4800	23.131	207.466	949.904	649.859	371.572
43481	31322	5400	23.751	207.776	945.872	640.993	360.913
43430	36852	6000	23.501	206.592	929.807	630.373	353.543
48583	34016	6000	24.467	253.803	1095.034	740.543	409.800
48557	30716	5400	24.843	254.428	1094.083	744.670	413.851
48631	27854	4800	25.251	254.388	1090.197	737.815	412.309
48613	24448	4200	25.548	254.768	1089.342	741.107	412.774
48565	20977	3600	25.255	254.485	1093.204	747.731	414.728
50123	20933	3600	25.834	268.138	1156.219	790.484	438.641
50167	24455	4200	27.352	270.011	1141.570	780.392	432.511
50116	27873	4800	27.636	269.538	1133.565	780.220	430.177
50214	30974	5400	27.408	271.247	1139.943	783.025	432.972
50194	34512	6000	27.514	270.084	1135.450	780.354	432.819

Table 10. Engine Operating Temperatures in Degrees Fahrenheit.

N1	N2	N3	T2 Inlet	T3 Outlet	T4	T5	T7
RPM	RPM	RPM	Fahrenheit	Fahrenheit	Fahrenheit	Fahrenheit	Fahrenheit
43440	20941	3600	70.280	401.841	1771.796	1211.598	691.614
43400	24467	4200	72.871	403.394	1748.094	1196.056	701.956
43460	27873	4800	73.635	405.439	1741.827	1201.746	700.830
43481	31322	5400	74.751	405.996	1734.569	1185.787	681.643
43430	36852	6000	74.302	403.865	1705.652	1166.671	668.378
48583	34016	6000	76.041	488.845	2003.061	1364.977	769.639
48557	30716	5400	76.717	489.970	2001.349	1372.406	776.931
48631	27854	4800	77.452	489.898	1994.354	1360.067	774.156
48613	24448	4200	77.986	490.582	1992.816	1365.993	774.993
48565	20977	3600	77.459	490.072	1999.768	1377.916	778.511
50123	20933	3600	78.501	514.648	2113.195	1454.871	821.553

50167	24455	4200	81.233	518.019	2086.827	1436.706	810.520
50116	27873	4800	81.745	517.168	2072.417	1436.396	806.319
50214	30974	5400	81.334	520.244	2083.897	1441.445	811.350
50194	34512	6000	81.525	518.150	2075.809	1436.637	811.074

Table 11. Engine Operating Pressures in KPa.

N1	N2	N3	PT2	P2	PT3	PT4	PT5	PT7
RPM	RPM	RPM	KPa	KPa	KPa	KPa	KPa	KPa
43440	20941	3600	99.402	73.317	393.646	380.977	160.241	105.758
43400	24467	4200	99.409	73.328	389.881	377.302	159.079	106.213
43460	27873	4800	99.402	73.319	391.353	378.798	159.269	106.467
43481	31322	5400	99.381	73.342	389.592	376.957	158.069	106.388
43430	36852	6000	99.374	73.328	386.479	373.341	155.825	106.408
48583	34016	6000	98.326	71.924	488.928	471.315	185.983	107.889
48557	30716	5400	98.292	71.926	488.697	472.074	186.124	107.372
48631	27854	4800	98.361	71.981	485.884	468.964	185.079	106.815
48613	24448	4200	98.366	71.984	486.270	469.081	185.152	107.543
48565	20977	3600	98.404	71.981	486.535	469.171	185.859	107.333
50123	20933	3600	98.030	71.457	516.290	497.953	195.339	107.814
50167	24455	4200	97.945	71.503	513.291	494.702	193.129	103.807
50116	27873	4800	97.979	71.538	512.046	493.896	192.598	103.587
50214	30974	5400	97.841	71.483	515.848	497.233	193.801	107.431
50194	34512	6000	97.919	71.533	512.677	494.275	192.791	108.446

Table 12. Engine Operating Pressures in PSIA.

N1	N2	N3	PT2	P2	PT3	PT4	PT5	PT7
RPM	RPM	RPM	PSIA	PSIA	PSIA	PSIA	PSIA	PSIA
43440	20941	3600	14.417	10.634	57.094	55.256	23.241	15.339
43400	24467	4200	14.418	10.635	56.548	54.723	23.073	15.405
43460	27873	4800	14.417	10.634	56.761	54.940	23.100	15.442
43481	31322	5400	14.414	10.637	56.506	54.673	22.926	15.430
43430	36852	6000	14.413	10.635	56.054	54.149	22.601	15.433
48583	34016	6000	14.261	10.432	70.913	68.359	26.975	15.648
48557	30716	5400	14.256	10.432	70.880	68.469	26.995	15.573
48631	27854	4800	14.266	10.440	70.472	68.018	26.844	15.492
48613	24448	4200	14.267	10.440	70.528	68.035	26.854	15.598
48565	20977	3600	14.272	10.440	70.566	68.048	26.957	15.567
50123	20933	3600	14.218	10.364	74.882	72.222	28.332	15.637
50167	24455	4200	14.206	10.371	74.447	71.751	28.011	15.056
50116	27873	4800	14.211	10.376	74.266	71.634	27.934	15.024
50214	30974	5400	14.191	10.368	74.818	72.118	28.109	15.582
50194	34512	6000	14.202	10.375	74.358	71.689	27.962	15.729

Table 13. Various Engine Parameters in SI Units.

N1	N2	N3	Torque	Engine Power	Air Flow	Fuel Flow	F/A ratio	η	BSFC
RPM	RPM	RPM	N-m	kW	M^3/sec	Kg/hr	ratio	Unitless	kg/kW-hr
43440	20941	3600	183.714	69.276	0.935	48.457	0.01195	0.324	0.699
43400	24467	4200	158.631	69.947	0.943	47.187	0.01160	0.350	0.675
43460	27873	4800	140.192	70.618	0.952	47.051	0.01149	0.361	0.666
43481	31322	5400	121.210	68.381	0.946	46.416	0.01145	0.360	0.679
43430	36852	6000	101.415	63.757	0.942	45.236	0.01117	0.364	0.710
48583	34016	6000	206.491	129.528	1.097	67.015	0.01428	0.390	0.517
48557	30716	5400	228.185	129.006	1.096	66.425	0.01423	0.403	0.515
48631	27854	4800	249.200	125.278	1.098	65.835	0.01412	0.409	0.526
48613	24448	4200	272.520	119.834	1.100	65.472	0.01400	0.413	0.546
48565	20977	3600	299.907	113.048	1.099	65.971	0.01416	0.409	0.584
50123	20933	3600	340.989	128.559	1.150	74.093	0.01516	0.418	0.576
50167	24455	4200	308.313	135.568	1.153	72.142	0.01483	0.433	0.532
50116	27873	4800	280.926	140.937	1.152	71.688	0.01476	0.434	0.509
50214	30974	5400	261.267	147.723	1.159	73.004	0.01496	0.434	0.494
50194	34512	6000	234.964	147.649	1.158	72.096	0.01478	0.438	0.488

Table 14. Various Engine Parameters in Imperial Units.

N1	N2	N3	Torque	BHP	Air Flow	Fuel Flow	F/A ratio	η	BSFC
RPM	RPM	RPM	lb-ft	HP	CFM	Lb/hr	ratio	Unitless	Lb/hp-hr
43440	20941	3600	135.5	92.9	1981.3	106.8	0.01195	0.324	1.150
43400	24467	4200	117	93.8	1998.7	104	0.01160	0.350	1.109
43460	27873	4800	103.4	94.7	2016.2	103.7	0.01149	0.361	1.095
43481	31322	5400	89.4	91.7	2003.7	102.3	0.01145	0.360	1.115
43430	36852	6000	74.8	85.5	1996.9	99.7	0.01117	0.364	1.167
48583	34016	6000	152.3	173.7	2324.1	147.7	0.01428	0.390	0.854
48557	30716	5400	168.3	173	2323.1	146.4	0.01423	0.403	0.846
48631	27854	4800	183.8	168	2325.5	145.1	0.01412	0.409	0.864
48613	24448	4200	201	160.7	2331.3	144.3	0.01400	0.413	0.898
48565	20977	3600	221.2	151.6	2328.8	145.4	0.01416	0.409	0.959
50123	20933	3600	251.5	172.4	2437.4	163.3	0.01516	0.418	0.947
50167	24455	4200	227.4	181.8	2443.7	159	0.01483	0.433	0.874
50116	27873	4800	207.2	189	2440.4	158	0.01476	0.434	0.836
50214	30974	5400	192.7	198.1	2455.8	160.9	0.01496	0.434	0.812
50194	34512	6000	198	198	2454.6	158.9	0.01478	0.438	0.803

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APPENDIX C. GASTURB DATA FILE OUTPUT

	W	T	P	WRstd			
Station	kg/s	K	KPa	kg/s	PWSD	=	144.6 kW
amb		288.15	101.325				
1	1.417	288.15	101.325		PSFC	=	0.6104 kg/(kW*h)
2	1.417	288.15	101.325	1.420	Heat Rate	=	26323.3 kJ/(kW*h)
3	1.403	583.85	623.149	0.325	V0	=	0.00 m/s
31	1.325	583.85	623.149		FN res	=	0.17 kN
4	1.350	1250.00	604.454	0.472	WF	=	0.02452 kg/s
41	1.350	1250.00	604.454	0.472	s NOx	=	0.17124
43	1.350	985.71	173.944		Therm Eff	=	0.13676
44	1.421	966.84	173.944		P45/P44	=	0.97500
45	1.421	966.84	169.595	1.557			
49	1.421	877.30	106.495		Incidence	=	0.00000 °
5	1.435	873.50	106.495	2.381	P6/P5	=	0.98000
6	1.435	873.50	104.365		PWX	=	0 kW
8	1.435	873.50	104.365	2.430	P8/Pamb	=	1.03000
Bleed	0.007	583.85	623.146		WBld/W2	=	0.00500

--- A8 = 0.02905 m²

Efficiencies:	isentr	polytr	RNI	P/P			
					TRQ	=	100.0 %
Compressor	0.6500	0.7236	1.000	6.150	P2/P1	=	1.00000
Burner	0.9990			0.970	Loading	=	100.00 %

HP Turbine 0.8200 0.7964 1.070 3.475 e444 th = 0.80042

LP Turbine 0.8500 0.8423 0.403 1.593 WHcl/W2 = 0.05000

Generator 1.0000 PW_gen = 144.6 kW

HP Spool mech Eff 0.9980 Nom Spd 10000 rpm WLcl/W2 = 0.01000

PT Spool mech Eff 0.9780 Nom Spd 20000 rpm eta t-s = 0.77260

Ps0-P2= 0.000 Ps8-Ps0= 0.000 Ps8 = 101.325 KPa

hum [%] war0 FHV Fuel

60.0 0.00637 43.124 Generic

Input Data File:

D:\files_backup\NPS\Marine Propulsion\Labs\Allison_250_V11_Power_Gen.CYS (modified)

APPENDIX D. SAMPLE ANSYS SOLUTION REPORT

Date

2016/10/23 16:05:47

Contents

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1. File Report

Table 1. File Information for CFX

Case	CFX
File Path	G:\VanDenBerg\October17_16\inflation layer runs\17_layers_files\dp0\CFX\CFX\Fluid Flow CFX_001.res
File Date	21 October 2016
File Time	10:48:55 AM
File Type	CFX5
File Version	16.2

2. Mesh Report

Table 2. Mesh Information for CFX

Domain	Nodes	Elements
Default Domain	517705	1128615

3. Physics Report

Table 3. Domain Physics for CFX

Domain - Default Domain	
Type	Fluid
Location	B17
Materials	
Air Ideal Gas	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant
Domain Motion	Stationary
Reference Pressure	0.0000e+00 [Pa]
Heat Transfer Model	Total Energy
Include Viscous Work Term	Off
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable

	High Speed Model	Off

Table 4. Boundary Physics for CFX

Domain	Boundaries	
Default Domain	Boundary - Exhaust_In	
	Type	INLET
	Location	Exhaust_In
	Settings	
	Flow Direction	Normal to Boundary Condition
	Flow Regime	Subsonic
	Heat Transfer	Total Temperature
	Total Temperature	7.5000e+02 [K]
	Mass And Momentum	Mass Flow Rate
	Mass Flow Rate	7.1000e-01 [kg s^-1]
	Mass Flow Rate Area	As Specified
	Turbulence	Medium Intensity and Eddy Viscosity Ratio
	Boundary - Exhaust_Out	
	Type	OUTLET
	Location	Exhaust_Out
	Settings	
	Flow Regime	Subsonic
	Mass And Momentum	Average Static Pressure
	Pressure Profile Blend	5.0000e-02
	Relative Pressure	1.0135e+05 [Pa]
	Pressure Averaging	Average Over Whole Outlet
	Boundary - Default Domain Default	
	Type	WALL
	Location	F19.17, F20.17, F21.17, F22.17, F23.17, F24.17, F26.17, F27.17, F28.17, F29.17, F30.17, F31.17
	Settings	
	Heat Transfer	Adiabatic
	Mass And	No Slip Wall

Momentum	
Wall Roughness	Smooth Wall

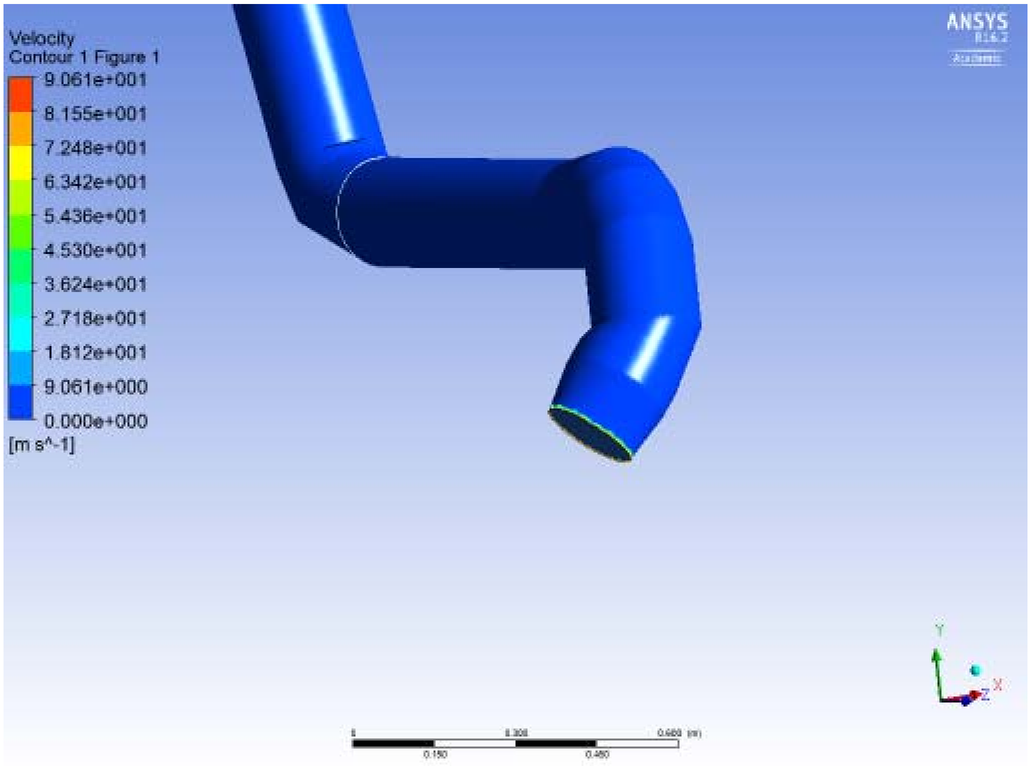
4. Solution Report

Table 5. Boundary Flows for CFX

Location	Type	Mass Flow	Momentum X	Y	Z
Default Domain Default	Boundary	0.0000e+00	-1.2000e+03	1.5248e+03	-7.8114e+02
Exhaust_In	Boundary	7.1000e-01	1.1920e+03	1.2966e+03	9.2246e+00
Exhaust_Out	Boundary	-7.1000e-01	8.0679e+00	-2.8214e+03	7.7191e+02

5. User Data

Figure 1.



APPENDIX E. SOLIDWORKS DRAWINGS OF FINALIZED HEAT EXCHANGER DESIGN

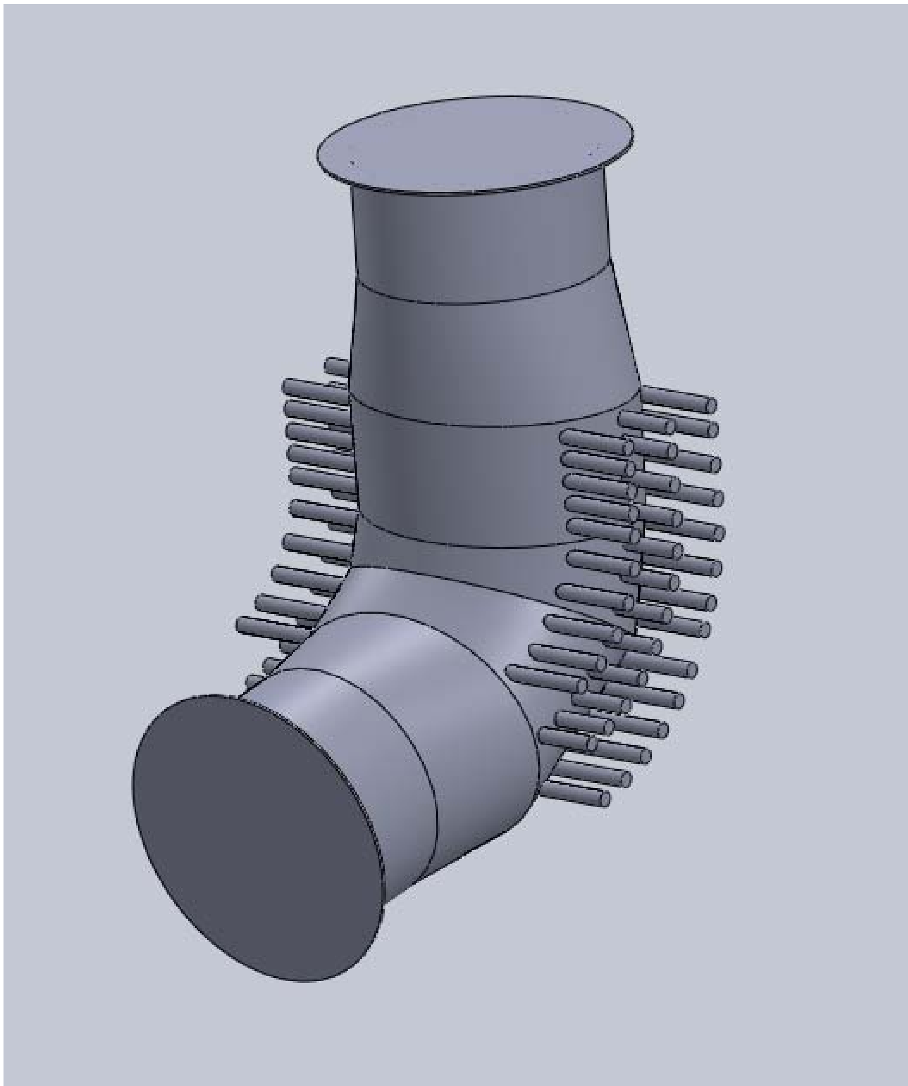


Figure 45. SolidWorks Model of Heat Exchanger with Tubes.

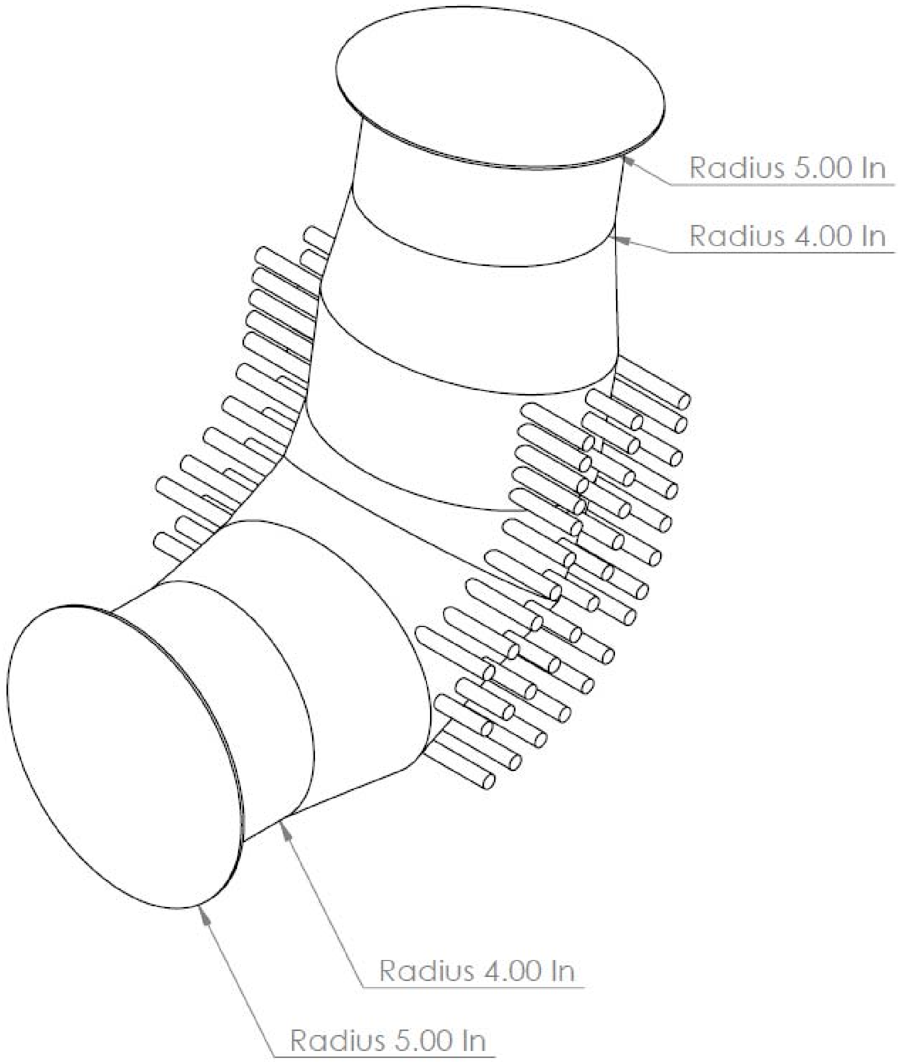


Figure 46. Isometric SolidWorks Drawing of Heat Exchanger.

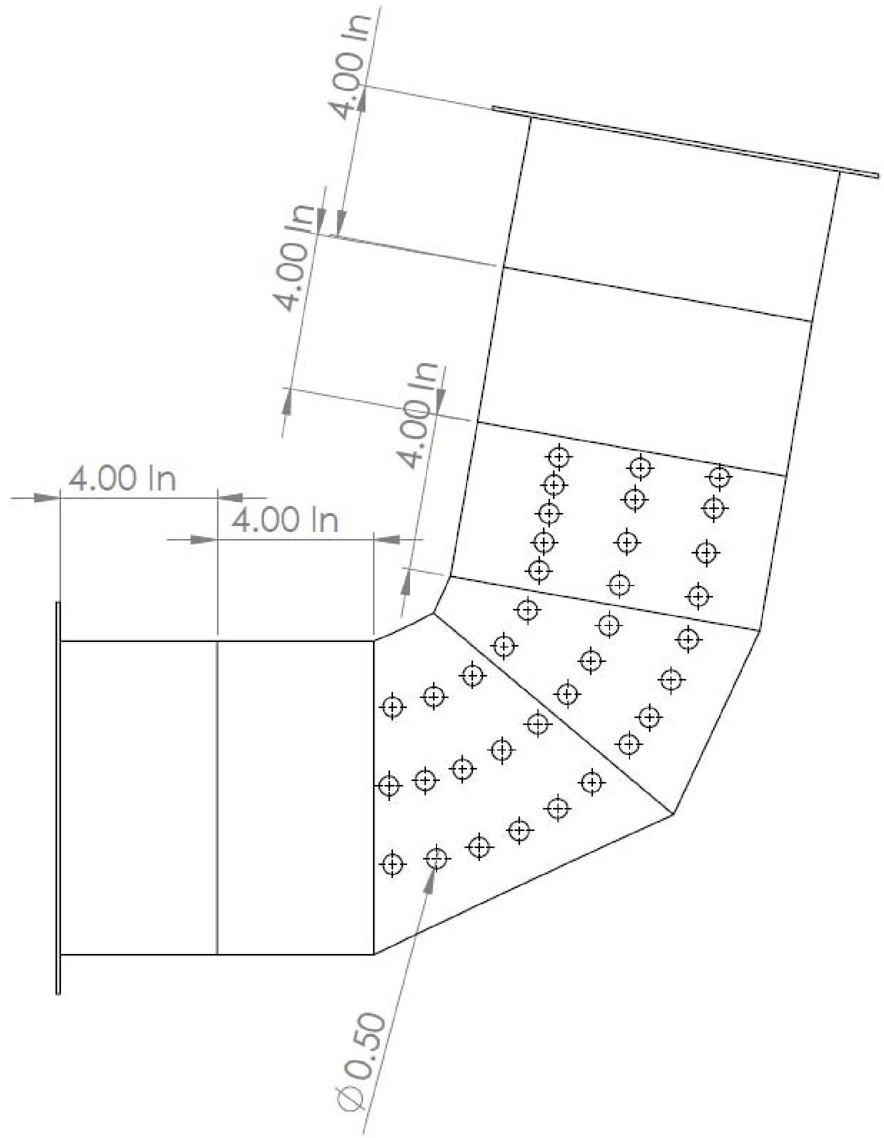


Figure 47. Right Orthographic SolidWorks Drawing of Heat Exchanger.

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APPENDIX F. RAW DATA FOR RANKINECYCLER™ DATA RUNS

Table 15. Raw Data for RankineCycler™ Factory Run.

Variable	Average value
Boiler Temperature	179.24 °C (354.63 °F)
Turbine Inlet Temperature	118.71 °C (245.68 °F)
Turbine Exit Temperature	106.24 °C (223.23 °F)
Boiler Pressure	868.12 KPa (125.91 psia)
Turbine Inlet Pressure	186.85 KPa (27.4 psia)
Turbine Exit Pressure	123.62 KPa (17.93 psia)
Boiler Entropy	6.6648 KJ/Kg*K (1.5929 Btu/lbm*R)
Turbine Inlet Entropy	7.1531 KJ/Kg*K (1.7083 Btu/lbm*R)
Turbine Exit Entropy	7.291 KJ/Kg*K (1.7426 Btu/lbm*R)
Boiler Enthalpy	2785.6 KJ/Kg (1198.4 Btu/lbm)
Turbine Inlet Enthalpy	2704.5 KJ/Kg (1163.4 Btu/lbm)
Turbine Exit Enthalpy	2685.6 KJ/Kg (1155.4 Btu/lbm)
Fuel Flow	5.28 L/min (1.4 Gal/min)
Generator Speed	1841.45 RPM
Generator Voltage	7.43 volts
Generator Current	0.27 amps
Generator Power	2.01 Watts

Table 16. Raw Data for RankineCycler™ Operational Run 1.

Variable	Average value
Boiler Temperature	187.8 °C (369.78 °F)
Turbine Inlet Temperature	123.69 °C (254.38 °F)
Turbine Exit Temperature	110.85 °C (231.26 °F)
Boiler Pressure	876.32 KPa (127.1 psia)
Turbine Inlet Pressure	180.85 KPa (26.23 psia)
Turbine Exit Pressure	120.93 KPa (17.54 psia)
Boiler Entropy	6.7052 KJ/Kg*K (1.6026 Btu/lbm*R)
Turbine Inlet Entropy	7.1958 KJ/Kg*K (1.7198 Btu/lbm*R)
Turbine Exit Entropy	7.3263 KJ/Kg*K (1.7510 Btu/lbm*R)
Boiler Enthalpy	2805.9 KJ/Kg (1207.1 Btu/lbm)
Turbine Inlet Enthalpy	2715.5 KJ/Kg (1168.2 Btu/lbm)
Turbine Exit Enthalpy	2695.3 KJ/Kg (1159.5 Btu/lbm)
Fuel Flow	5.12 L/min (1.35 Gal/min)
Generator Speed	1999.08 RPM
Generator Voltage	8.25 volts
Generator Current	0.2 amps
Generator Power	1.64 Watts

Table 17. Raw Data for RankineCycler^{TM} Operational Run 2.

Variable	Average value
Boiler Temperature	187.8 °C (369.78 °F)
Turbine Inlet Temperature	123.69 °C (254.38 °F)
Turbine Exit Temperature	110.85 °C (231.26 °F)
Boiler Pressure	839.40 KPa (121.60 psia)
Turbine Inlet Pressure	185.12 KPa (26.85 psia)
Turbine Exit Pressure	122.04 KPa (17.70 psia)
Boiler Entropy	6.7166 KJ/Kg*K (1.6057 Btu/lbm*R)
Turbine Inlet Entropy	7.1752 KJ/Kg*K (1.7151 Btu/lbm*R)
Turbine Exit Entropy	7.3204 KJ/Kg*K (1.7498 Btu/lbm*R)
Boiler Enthalpy	2802.5 KJ/Kg (1205.9 Btu/lbm)
Turbine Inlet Enthalpy	2711.5 KJ/Kg (1166.7 Btu/lbm)
Turbine Exit Enthalpy	2694.6 KJ/Kg (1159.4 Btu/lbm)
Fuel Flow	5.15 L/min (1.36 Gal/min)
Generator Speed	2056.43 RPM
Generator Voltage	8.37 volts
Generator Current	0.22 amps
Generator Power	1.83 Watts

Table 18. Raw Data for RankineCycler^{TM} Operational Run 3.

Variable	Average value
Boiler Temperature	184.46 °C (364.02 °F)
Turbine Inlet Temperature	122.12 °C (251.82 °F)
Turbine Exit Temperature	111.57 °C (232.83 °F)
Boiler Pressure	836.68 KPa (121.35 psia)
Turbine Inlet Pressure	187.81 KPa (27.24 psia)
Turbine Exit Pressure	123.07 KPa (17.85 psia)
Boiler Entropy	6.7134 KJ/Kg*K (1.6047 Btu/lbm*R)
Turbine Inlet Entropy	7.1684 KJ/Kg*K (1.7135 Btu/lbm*R)
Turbine Exit Entropy	7.3215 KJ/Kg*K (1.7501 Btu/lbm*R)
Boiler Enthalpy	2800.4 KJ/Kg (1204.9 Btu/lbm)
Turbine Inlet Enthalpy	2711.4 KJ/Kg (1166.6 Btu/lbm)
Turbine Exit Enthalpy	2696.5 KJ/Kg (1160.2 Btu/lbm)
Fuel Flow	5.19 L/min (1.37 Gal/min)
Generator Speed	2012.22 RPM
Generator Voltage	8.22 volts
Generator Current	0.26 amps
Generator Power	2.14 Watts

Table 19. Raw Data for RankineCycler™ Operational Run 4.

Variable	Average value
Boiler Temperature	181.95 °C (359.50 °F)
Turbine Inlet Temperature	119.38 °C (246.89 °F)
Turbine Exit Temperature	108.93 °C (228.07 °F)
Boiler Pressure	865.71 KPa (125.56 psia)
Turbine Inlet Pressure	188.92 KPa (27.40 psia)
Turbine Exit Pressure	123.42 KPa (17.90 psia)
Boiler Entropy	6.6806 KJ/Kg*K (1.5969 Btu/lbm*R)
Turbine Inlet Entropy	7.1504 KJ/Kg*K (1.7092 Btu/lbm*R)
Turbine Exit Entropy	7.3058 KJ/Kg*K (1.7463 Btu/lbm*R)
Boiler Enthalpy	2792.2 KJ/Kg (1201.4 Btu/lbm)
Turbine Inlet Enthalpy	2705.4 KJ/Kg (1164.0 Btu/lbm)
Turbine Exit Enthalpy	2691.0 KJ/Kg (1157.8 Btu/lbm)
Fuel Flow	5.11 L/min (1.35 Gal/min)
Generator Speed	2119.18 RPM
Generator Voltage	8.59 volts
Generator Current	0.27 amps
Generator Power	2.38 Watts

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APPENDIX G. CALCULATED DATA FOR RANKINE, TRANSCRITICAL AND BRAYTON WHR CYCLES

Table 20. All Calculated Rankine Cycle Parameters Using LM2500 Heat Rate.

	Parameter	Value
Pump:	Temperature In	253.65K
	Enthalpy In	155.52 kJ/kg
	Entropy In	0.837 kJ/kg*K
	Temperature Out	254.7K
	Enthalpy Out	157.57 kJ/kg
	Entropy Out	0.837 kJ/kg*K
Boiler:	Temperature In	254.7K
	Enthalpy In	157.57 kJ/kg
	Entropy In	0.837 kJ/kg*K
	Temperature Out	301.9K
	Enthalpy Out	465.32 kJ/kg
	Entropy Out	1.9461 kJ/kg*K
Turbine:	Temperature In	301.9K
	Enthalpy In	465.32 kJ/kg
	Entropy In	1.9461 kJ/kg*K
	Temperature Out	253.65K
	Enthalpy Out	436.85 kJ/kg
	Entropy Out	1.9461 kJ/kg*K
Condenser:	Temperature In	253.65K
	Enthalpy In	436.85 kJ/kg
	Entropy In	1.9461 kJ/kg*K
	Temperature Out	253.65K
	Enthalpy Out	155.52 kJ/kg
	Entropy Out	0.837 kJ/kg*K
Cycle:	Mass Flow Rate	9.57 kg/s
	Pump Power	19.6 kW
	Boiler Heat Rate	2946 kW
	Turbine Power	273 kW
	Condenser Heat Rate	2693 kW
	Total Power Out	253 kW
	Efficiency	8.6%

Table 21. All Calculated Transcritical Rankine Cycle Parameters Using LM2500 Heat Rate.

	Parameter	Value
Pump:	Temperature In	295.13K
	Enthalpy In	262.85 kJ/kg
	Entropy In	1.21 kJ/kg*K
	Temperature Out	304.8K
	Enthalpy Out	270.69 kJ/kg
	Entropy Out	1.21 kJ/kg*K
Boiler:	Temperature In	304.8K
	Enthalpy In	270.69 kJ/kg
	Entropy In	1.21 kJ/kg*K
	Temperature Out	750K
	Enthalpy Out	952.88 kJ/kg
	Entropy Out	2.735 kJ/kg*K
Turbine:	Temperature In	750K
	Enthalpy In	952.88 kJ/kg
	Entropy In	2.735 kJ/kg*K
	Temperature Out	664.2K
	Enthalpy Out	860.19 kJ/kg
	Entropy Out	2.735 kJ/kg*K
Condenser:	Temperature In	664.2K
	Enthalpy In	860.19 kJ/kg
	Entropy In	2.735 kJ/kg*K
	Temperature Out	295.13K
	Enthalpy Out	262.85 kJ/kg
	Entropy Out	1.21 kJ/kg*K
Cycle:	Mass Flow Rate	19.1 kg/s
	Pump Power	150 kW
	Boiler Heat Rate	2946 kW
	Turbine Power	1772 kW
	Condenser Heat Rate	1324 kW
	Total Power Out	1622 kW
	Efficiency	55.1%

Table 22. All Calculated Brayton Cycle Parameters Using LM2500 Heat Rate.

	Parameter	Value
Compressor:	Temperature In	300K
	Enthalpy In	507.43 kJ/kg
	Entropy In	2.7446 kJ/kg*K
	Temperature Out	349K
	Enthalpy Out	549.64 kJ/kg
	Entropy Out	2.7446 kJ/kg*K
Boiler:	Temperature In	349K
	Enthalpy In	549.64 kJ/kg
	Entropy In	2.7446 kJ/kg*K
	Temperature Out	750K
	Enthalpy Out	966.93 kJ/kg
	Entropy Out	3.5286 kJ/kg*K
Turbine:	Temperature In	750K
	Enthalpy In	966.93 kJ/kg
	Entropy In	3.5286 kJ/kg*K
	Temperature Out	668K
	Enthalpy Out	874.17 kJ/kg
	Entropy Out	3.5286 kJ/kg*K
Condenser:	Temperature In	668K
	Enthalpy In	874.17 kJ/kg
	Entropy In	3.5286 kJ/kg*K
	Temperature Out	300K
	Enthalpy Out	507.43 kJ/kg
	Entropy Out	2.7446 kJ/kg*K
Cycle:	Mass Flow Rate	26.1 kg/s
	Pump Power	1103 kW
	Boiler Heat Rate	2946 kW
	Turbine Power	2425 kW
	Condenser Heat Rate	1624 kW
	Total Power Out	1321 kW
	Efficiency	45%

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APPENDIX H. CARBON DIOXIDE TABLES FOR T-S DIAGRAM

Table 23. Isobaric CO_2 Properties at 0.1 MPa. Source: [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (uPa*s)	Therm. Cond. (W/m*K)	Phase
220	0.1	2.4394	0.40993	401.24	442.23	2.4924	0.57907	0.78067	233.45	24.907	11.063	0.010902	vapor
230	0.1	2.3288	0.4294	407.13	450.07	2.5273	0.58833	0.78795	238.38	21.935	11.565	0.01156	vapor
240	0.1	2.2282	0.44878	413.12	457.99	2.561	0.59811	0.79617	243.15	19.468	12.066	0.012243	vapor
250	0.1	2.1363	0.4681	419.19	466	2.5937	0.60818	0.80501	247.79	17.399	12.565	0.01295	vapor
260	0.1	2.0519	0.48736	425.36	474.1	2.6254	0.61843	0.81424	252.31	15.646	13.061	0.013681	vapor
270	0.1	1.9741	0.50657	431.63	482.29	2.6563	0.62872	0.82371	256.72	14.148	13.555	0.014433	vapor
280	0.1	1.9021	0.52574	438	490.57	2.6864	0.639	0.8333	261.03	12.858	14.047	0.015204	vapor
290	0.1	1.8352	0.54489	444.46	498.95	2.7159	0.64922	0.84293	265.25	11.739	14.536	0.01599	vapor
300	0.1	1.773	0.56401	451.03	507.43	2.7446	0.65932	0.85253	269.39	10.761	15.021	0.016791	vapor
310	0.1	1.715	0.5831	457.69	516	2.7727	0.66928	0.86207	273.46	9.9024	15.504	0.017603	vapor
320	0.1	1.6606	0.60218	464.45	524.67	2.8002	0.67908	0.87151	277.45	9.1437	15.983	0.018424	vapor
330	0.1	1.6097	0.62124	471.31	533.43	2.8272	0.68871	0.88083	281.37	8.4699	16.46	0.019252	vapor
340	0.1	1.5618	0.64028	478.26	542.29	2.8536	0.69816	0.89001	285.24	7.8685	16.932	0.020086	vapor
350	0.1	1.5167	0.65931	485.3	551.23	2.8795	0.70743	0.89903	289.04	7.3293	17.402	0.020924	vapor
360	0.1	1.4742	0.67833	492.43	560.27	2.905	0.71651	0.9079	292.79	6.844	17.868	0.021766	vapor
370	0.1	1.434	0.69734	499.65	569.39	2.93	0.72541	0.91661	296.49	6.4053	18.33	0.022609	vapor
380	0.1	1.396	0.71635	506.96	578.6	2.9545	0.73412	0.92515	300.13	6.0074	18.789	0.023453	vapor
390	0.1	1.3599	0.73534	514.36	587.89	2.9787	0.74264	0.93352	303.73	5.6451	19.244	0.024298	vapor
400	0.1	1.3257	0.75433	521.84	597.27	3.0024	0.75099	0.94173	307.28	5.3144	19.696	0.025143	vapor
410	0.1	1.2931	0.77331	529.4	606.73	3.0258	0.75916	0.94978	310.79	5.0114	20.144	0.025986	vapor
420	0.1	1.2622	0.79228	537.04	616.26	3.0488	0.76716	0.95767	314.25	4.7332	20.589	0.026829	vapor
430	0.1	1.2327	0.81125	544.75	625.88	3.0714	0.77499	0.9654	317.68	4.4769	21.029	0.02767	vapor
440	0.1	1.2045	0.83021	552.55	635.57	3.0937	0.78266	0.97298	321.06	4.2402	21.467	0.028509	vapor
450	0.1	1.1776	0.84918	560.42	645.34	3.1156	0.79017	0.98041	324.41	4.0212	21.901	0.029346	vapor
460	0.1	1.1519	0.86813	568.37	655.18	3.1372	0.79753	0.9877	327.72	3.8181	22.331	0.03018	vapor
470	0.1	1.1273	0.88708	576.38	665.09	3.1586	0.80474	0.99484	330.99	3.6292	22.758	0.031012	vapor
480	0.1	1.1037	0.90603	584.47	675.07	3.1796	0.8118	1.0018	334.24	3.4532	23.181	0.031841	vapor
490	0.1	1.0811	0.92498	592.63	685.13	3.2003	0.81873	1.0087	337.44	3.289	23.601	0.032667	vapor
500	0.1	1.0594	0.94392	600.86	695.25	3.2208	0.82552	1.0154	340.62	3.1355	24.017	0.033491	vapor
510	0.1	1.0386	0.96286	609.15	705.44	3.2409	0.83217	1.022	343.77	2.9917	24.43	0.034311	vapor
520	0.1	1.0185	0.9818	617.51	715.69	3.2608	0.8387	1.0285	346.88	2.8568	24.84	0.035129	vapor
530	0.1	0.99926	1.0007	625.93	726.01	3.2805	0.8451	1.0349	349.97	2.73	25.246	0.035943	vapor
540	0.1	0.98071	1.0197	634.42	736.39	3.2999	0.85138	1.0411	353.03	2.6107	25.649	0.036754	vapor
550	0.1	0.96283	1.0386	642.97	746.83	3.3191	0.85755	1.0472	356.06	2.4983	26.048	0.037562	vapor
560	0.1	0.94559	1.0575	651.58	757.33	3.338	0.86359	1.0533	359.06	2.3922	26.445	0.038367	vapor
570	0.1	0.92897	1.0765	660.25	767.89	3.3567	0.86953	1.0592	362.04	2.292	26.838	0.039169	vapor

580	0.1	0.91292	1.0954	668.97	778.51	3.3751	0.87535	1.065	364.99	2.1971	27.228	0.039967	vapor
590	0.1	0.89741	1.1143	677.76	789.19	3.3934	0.88107	1.0706	367.92	2.1073	27.615	0.040762	vapor
600	0.1	0.88242	1.1332	686.6	799.93	3.4114	0.88668	1.0762	370.83	2.0221	27.999	0.041554	vapor
610	0.1	0.86793	1.1522	695.5	810.72	3.4293	0.89219	1.0817	373.71	1.9412	28.379	0.042343	vapor
620	0.1	0.85391	1.1711	704.45	821.56	3.4469	0.8976	1.0871	376.57	1.8643	28.757	0.043129	vapor
630	0.1	0.84033	1.19	713.46	832.46	3.4643	0.90291	1.0924	379.4	1.7912	29.132	0.043911	vapor
640	0.1	0.82718	1.2089	722.52	843.41	3.4816	0.90813	1.0976	382.22	1.7215	29.504	0.04469	vapor
650	0.1	0.81444	1.2278	731.62	854.41	3.4986	0.91325	1.1027	385.01	1.6551	29.873	0.045466	vapor
660	0.1	0.80208	1.2468	740.79	865.46	3.5155	0.91828	1.1077	387.79	1.5918	30.239	0.046238	vapor
670	0.1	0.79009	1.2657	750	876.56	3.5322	0.92322	1.1126	390.54	1.5313	30.602	0.047008	vapor
680	0.1	0.77846	1.2846	759.25	887.71	3.5487	0.92807	1.1175	393.27	1.4735	30.963	0.047773	vapor
690	0.1	0.76716	1.3035	768.56	898.91	3.5651	0.93284	1.1222	395.99	1.4182	31.321	0.048536	vapor
700	0.1	0.75619	1.3224	777.91	910.16	3.5813	0.93752	1.1269	398.68	1.3653	31.676	0.049296	vapor
710	0.1	0.74552	1.3413	787.32	921.45	3.5973	0.94211	1.1314	401.36	1.3146	32.029	0.050052	vapor
720	0.1	0.73516	1.3602	796.76	932.79	3.6131	0.94663	1.136	404.02	1.2661	32.378	0.050805	vapor
730	0.1	0.72508	1.3792	806.25	944.17	3.6288	0.95106	1.1404	406.66	1.2194	32.726	0.051554	vapor
740	0.1	0.71527	1.3981	815.79	955.59	3.6444	0.95542	1.1447	409.28	1.1747	33.071	0.052301	vapor
750	0.1	0.70572	1.417	825.36	967.06	3.6598	0.95969	1.149	411.89	1.1317	33.413	0.053044	vapor
760	0.1	0.69643	1.4359	834.98	978.57	3.675	0.9639	1.1532	414.48	1.0904	33.753	0.053783	vapor
770	0.1	0.68738	1.4548	844.64	990.12	3.6901	0.96802	1.1573	417.05	1.0507	34.09	0.05452	vapor
780	0.1	0.67856	1.4737	854.35	1001.7	3.7051	0.97208	1.1613	419.61	1.0124	34.425	0.055253	vapor
790	0.1	0.66996	1.4926	864.09	1013.4	3.7199	0.97606	1.1653	422.16	0.97559	34.758	0.055983	vapor
800	0.1	0.66158	1.5115	873.87	1025	3.7346	0.97997	1.1692	424.68	0.94011	35.088	0.05671	vapor
810	0.1	0.65341	1.5304	883.69	1036.7	3.7491	0.98381	1.173	427.2	0.9059	35.417	0.057433	vapor
820	0.1	0.64543	1.5493	893.55	1048.5	3.7635	0.98759	1.1768	429.7	0.8729	35.742	0.058154	vapor
830	0.1	0.63765	1.5683	903.45	1060.3	3.7778	0.99129	1.1805	432.18	0.84105	36.066	0.058871	vapor
840	0.1	0.63006	1.5872	913.38	1072.1	3.792	0.99493	1.1841	434.65	0.81029	36.388	0.059584	vapor
850	0.1	0.62264	1.6061	923.35	1084	3.806	0.99851	1.1877	437.11	0.78058	36.707	0.060295	vapor
860	0.1	0.6154	1.625	933.35	1095.8	3.8199	1.002	1.1912	439.55	0.75187	37.024	0.061002	vapor
870	0.1	0.60832	1.6439	943.39	1107.8	3.8337	1.0055	1.1947	441.98	0.7241	37.339	0.061706	vapor
880	0.1	0.6014	1.6628	953.46	1119.7	3.8474	1.0089	1.198	444.39	0.69723	37.652	0.062407	vapor
890	0.1	0.59464	1.6817	963.57	1131.7	3.861	1.0122	1.2014	446.8	0.67123	37.964	0.063105	vapor
900	0.1	0.58803	1.7006	973.71	1143.8	3.8744	1.0155	1.2046	449.19	0.64605	38.273	0.063799	vapor
910	0.1	0.58157	1.7195	983.88	1155.8	3.8877	1.0187	1.2078	451.56	0.62165	38.58	0.06449	vapor
920	0.1	0.57524	1.7384	994.08	1167.9	3.9009	1.0218	1.211	453.93	0.59801	38.885	0.065178	vapor
930	0.1	0.56906	1.7573	1004.3	1180	3.9141	1.025	1.2141	456.28	0.57509	39.189	0.065863	vapor
940	0.1	0.563	1.7762	1014.6	1192.2	3.9271	1.028	1.2171	458.62	0.55286	39.49	0.066545	vapor
950	0.1	0.55707	1.7951	1024.9	1204.4	3.94	1.031	1.2201	460.95	0.53129	39.79	0.067224	vapor
960	0.1	0.55127	1.814	1035.2	1216.6	3.9527	1.0339	1.2231	463.27	0.51035	40.088	0.0679	vapor
970	0.1	0.54558	1.8329	1045.6	1228.9	3.9654	1.0368	1.226	465.58	0.49002	40.384	0.068572	vapor
980	0.1	0.54001	1.8518	1055.9	1241.1	3.978	1.0397	1.2288	467.88	0.47027	40.678	0.069242	vapor
990	0.1	0.53456	1.8707	1066.4	1253.4	3.9905	1.0425	1.2316	470.16	0.45107	40.971	0.069908	vapor

1000	0.1	0.52921	1.8896	1076.8	1265.8	4.0029	1.0452	1.2343	472.43	0.43241	41.262	0.070571	vapor
1010	0.1	0.52397	1.9085	1087.3	1278.1	4.0152	1.0479	1.237	474.7	0.41427	41.551	0.071232	vapor
1020	0.1	0.51883	1.9274	1097.8	1290.5	4.0274	1.0506	1.2397	476.95	0.39662	41.839	0.071889	vapor
1030	0.1	0.51379	1.9463	1108.3	1302.9	4.0395	1.0532	1.2423	479.19	0.37945	42.125	0.072543	vapor
1040	0.1	0.50885	1.9652	1118.8	1315.3	4.0515	1.0557	1.2448	481.42	0.36274	42.409	0.073195	vapor
1050	0.1	0.504	1.9841	1129.4	1327.8	4.0634	1.0582	1.2473	483.65	0.34646	42.692	0.073843	vapor
1060	0.1	0.49925	2.003	1140	1340.3	4.0753	1.0607	1.2498	485.86	0.33061	42.973	0.074489	vapor
1070	0.1	0.49458	2.0219	1150.6	1352.8	4.087	1.0631	1.2522	488.06	0.31517	43.253	0.075131	vapor
1080	0.1	0.49	2.0408	1161.3	1365.3	4.0987	1.0655	1.2546	490.25	0.30011	43.531	0.075771	vapor
1090	0.1	0.4855	2.0597	1171.9	1377.9	4.1103	1.0679	1.257	492.44	0.28544	43.808	0.076408	vapor
1100	0.1	0.48109	2.0786	1182.6	1390.5	4.1218	1.0702	1.2593	494.61	0.27114	44.084	0.077042	vapor

Table 24. Isobaric CO_2 Properties at 0.2 MPa. Source [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (uPa*s)	Therm. Cond. (W/m*K)	Phase
220	0.2	4.9495	0.20204	399.85	440.26	2.3551	0.58993	0.80556	231.52	24.911	11.075	0.010968	vapor
230	0.2	4.7152	0.21208	405.91	448.32	2.3909	0.59692	0.80819	236.7	21.941	11.576	0.011622	vapor
240	0.2	4.5039	0.22203	412.02	456.43	2.4254	0.60502	0.81291	241.68	19.476	12.076	0.012301	vapor
250	0.2	4.312	0.23191	418.21	464.59	2.4587	0.61383	0.81906	246.49	17.407	12.575	0.013006	vapor
260	0.2	4.1369	0.24173	424.47	472.81	2.491	0.6231	0.82618	251.16	15.654	13.071	0.013734	vapor
270	0.2	3.9761	0.2515	430.81	481.11	2.5223	0.63263	0.83396	255.69	14.156	13.564	0.014483	vapor
280	0.2	3.828	0.26124	437.25	489.49	2.5528	0.64231	0.84219	260.1	12.865	14.056	0.015252	vapor
290	0.2	3.6909	0.27094	443.77	497.96	2.5825	0.65203	0.8507	264.42	11.744	14.544	0.016037	vapor
300	0.2	3.5636	0.28061	450.39	506.51	2.6115	0.66174	0.85938	268.64	10.766	15.029	0.016836	vapor
310	0.2	3.4451	0.29026	457.09	515.15	2.6398	0.67137	0.86815	272.77	9.9057	15.512	0.017646	vapor
320	0.2	3.3345	0.29989	463.89	523.87	2.6675	0.6809	0.87693	276.83	9.1458	15.991	0.018466	vapor
330	0.2	3.2309	0.30951	470.78	532.68	2.6946	0.6903	0.88569	280.81	8.471	16.467	0.019293	vapor
340	0.2	3.1337	0.31911	477.76	541.58	2.7212	0.69957	0.89438	284.73	7.8687	16.939	0.020125	vapor
350	0.2	3.0423	0.32869	484.83	550.57	2.7473	0.70867	0.903	288.58	7.3288	17.409	0.020962	vapor
360	0.2	2.9562	0.33827	491.99	559.64	2.7728	0.71762	0.91151	292.37	6.8428	17.874	0.021803	vapor
370	0.2	2.8749	0.34783	499.23	568.8	2.7979	0.72639	0.9199	296.1	6.4036	18.336	0.022645	vapor
380	0.2	2.7981	0.35739	506.56	578.04	2.8225	0.735	0.92816	299.78	6.0052	18.795	0.023488	vapor
390	0.2	2.7253	0.36694	513.98	587.36	2.8468	0.74343	0.9363	303.41	5.6426	19.25	0.024332	vapor
400	0.2	2.6562	0.37648	521.47	596.77	2.8706	0.7517	0.94429	306.99	5.3115	19.702	0.025176	vapor
410	0.2	2.5906	0.38601	529.05	606.25	2.894	0.75981	0.95215	310.52	5.0084	20.15	0.026019	vapor
420	0.2	2.5282	0.39554	536.7	615.81	2.917	0.76775	0.95987	314.01	4.7299	20.594	0.02686	vapor
430	0.2	2.4687	0.40506	544.43	625.45	2.9397	0.77553	0.96744	317.46	4.4735	21.035	0.027701	vapor
440	0.2	2.4121	0.41458	552.24	635.16	2.962	0.78315	0.97488	320.87	4.2367	21.472	0.028539	vapor
450	0.2	2.358	0.4241	560.12	644.94	2.984	0.79062	0.98219	324.23	4.0177	21.906	0.029375	vapor
460	0.2	2.3062	0.43361	568.08	654.8	3.0057	0.79794	0.98936	327.56	3.8144	22.336	0.030209	vapor
470	0.2	2.2568	0.44311	576.11	664.73	3.027	0.80512	0.99639	330.86	3.6256	22.763	0.03104	vapor
480	0.2	2.2094	0.45262	584.21	674.73	3.0481	0.81215	1.0033	334.11	3.4496	23.186	0.031868	vapor
490	0.2	2.164	0.46212	592.37	684.8	3.0688	0.81905	1.0101	337.34	3.2854	23.605	0.032694	vapor
500	0.2	2.1204	0.47161	600.61	694.93	3.0893	0.82582	1.0167	340.53	3.1319	24.022	0.033517	vapor
510	0.2	2.0785	0.48111	608.91	705.13	3.1095	0.83245	1.0233	343.69	2.9882	24.434	0.034337	vapor
520	0.2	2.0383	0.4906	617.27	715.4	3.1294	0.83896	1.0297	346.81	2.8533	24.844	0.035154	vapor
530	0.2	1.9996	0.50009	625.71	725.72	3.1491	0.84535	1.036	349.91	2.7266	25.25	0.035968	vapor
540	0.2	1.9624	0.50958	634.2	736.11	3.1685	0.85161	1.0422	352.98	2.6073	25.653	0.036778	vapor
550	0.2	1.9265	0.51906	642.75	746.57	3.1877	0.85776	1.0482	356.02	2.495	26.052	0.037586	vapor
560	0.2	1.892	0.52855	651.37	757.08	3.2067	0.86379	1.0542	359.03	2.3889	26.449	0.03839	vapor
570	0.2	1.8586	0.53803	660.04	767.65	3.2254	0.86971	1.0601	362.02	2.2888	26.842	0.039192	vapor
580	0.2	1.8264	0.54751	668.78	778.28	3.2439	0.87553	1.0658	364.98	2.194	27.232	0.03999	vapor
590	0.2	1.7954	0.55699	677.57	788.97	3.2621	0.88123	1.0715	367.92	2.1042	27.619	0.040785	vapor
600	0.2	1.7653	0.56647	686.41	799.71	3.2802	0.88684	1.077	370.83	2.019	28.002	0.041576	vapor

610	0.2	1.7363	0.57595	695.32	810.51	3.298	0.89234	1.0825	373.72	1.9382	28.383	0.042365	vapor
620	0.2	1.7082	0.58542	704.27	821.36	3.3157	0.89774	1.0878	376.59	1.8614	28.761	0.04315	vapor
630	0.2	1.681	0.5949	713.28	832.26	3.3331	0.90305	1.0931	379.43	1.7883	29.136	0.043932	vapor
640	0.2	1.6546	0.60437	722.34	843.22	3.3504	0.90825	1.0982	382.25	1.7188	29.507	0.04471	vapor
650	0.2	1.6291	0.61384	731.46	854.23	3.3674	0.91337	1.1033	385.05	1.6524	29.876	0.045486	vapor
660	0.2	1.6043	0.62331	740.62	865.29	3.3843	0.91839	1.1083	387.83	1.5892	30.242	0.046258	vapor
670	0.2	1.5803	0.63278	749.84	876.39	3.401	0.92333	1.1132	390.58	1.5288	30.606	0.047027	vapor
680	0.2	1.557	0.64225	759.1	887.55	3.4176	0.92817	1.118	393.32	1.471	30.966	0.047793	vapor
690	0.2	1.5344	0.65172	768.41	898.75	3.4339	0.93293	1.1227	396.04	1.4158	31.324	0.048555	vapor
700	0.2	1.5124	0.66119	777.77	910	3.4501	0.93761	1.1274	398.74	1.363	31.679	0.049314	vapor
710	0.2	1.4911	0.67066	787.17	921.3	3.4661	0.9422	1.132	401.42	1.3123	32.032	0.05007	vapor
720	0.2	1.4703	0.68012	796.62	932.64	3.482	0.94671	1.1364	404.08	1.2638	32.382	0.050823	vapor
730	0.2	1.4501	0.68959	806.11	944.03	3.4977	0.95114	1.1408	406.73	1.2173	32.729	0.051572	vapor
740	0.2	1.4305	0.69905	815.65	955.46	3.5132	0.95549	1.1452	409.36	1.1726	33.074	0.052318	vapor
750	0.2	1.4114	0.70852	825.23	966.93	3.5286	0.95977	1.1494	411.97	1.1297	33.416	0.053061	vapor
760	0.2	1.3928	0.71798	834.85	978.45	3.5439	0.96397	1.1536	414.56	1.0884	33.756	0.053801	vapor
770	0.2	1.3747	0.72745	844.51	990	3.559	0.96809	1.1577	417.14	1.0487	34.093	0.054537	vapor
780	0.2	1.357	0.73691	854.22	1001.6	3.574	0.97214	1.1617	419.7	1.0105	34.428	0.05527	vapor
790	0.2	1.3398	0.74637	863.96	1013.2	3.5888	0.97612	1.1657	422.25	0.97373	34.761	0.056	vapor
800	0.2	1.323	0.75583	873.75	1024.9	3.6035	0.98003	1.1696	424.78	0.93829	35.091	0.056726	vapor
810	0.2	1.3067	0.7653	883.57	1036.6	3.618	0.98387	1.1734	427.29	0.90412	35.419	0.057449	vapor
820	0.2	1.2907	0.77476	893.43	1048.4	3.6324	0.98764	1.1771	429.79	0.87117	35.745	0.058169	vapor
830	0.2	1.2752	0.78422	903.33	1060.2	3.6467	0.99135	1.1808	432.28	0.83936	36.069	0.058886	vapor
840	0.2	1.26	0.79368	913.26	1072	3.6609	0.99499	1.1845	434.75	0.80865	36.39	0.0596	vapor
850	0.2	1.2451	0.80314	923.23	1083.9	3.6749	0.99856	1.188	437.21	0.77898	36.71	0.06031	vapor
860	0.2	1.2306	0.8126	933.24	1095.8	3.6889	1.0021	1.1915	439.66	0.75031	37.027	0.061017	vapor
870	0.2	1.2165	0.82205	943.28	1107.7	3.7027	1.0055	1.195	442.09	0.72258	37.342	0.061721	vapor
880	0.2	1.2026	0.83151	953.35	1119.7	3.7163	1.0089	1.1983	444.5	0.69575	37.655	0.062422	vapor
890	0.2	1.1891	0.84097	963.46	1131.7	3.7299	1.0122	1.2016	446.91	0.66978	37.966	0.063119	vapor
900	0.2	1.1759	0.85043	973.6	1143.7	3.7433	1.0155	1.2049	449.3	0.64464	38.275	0.063814	vapor
910	0.2	1.1629	0.85989	983.78	1155.8	3.7567	1.0187	1.2081	451.68	0.62028	38.582	0.064505	vapor
920	0.2	1.1503	0.86934	993.98	1167.9	3.7699	1.0219	1.2113	454.05	0.59667	38.888	0.065193	vapor
930	0.2	1.1379	0.8788	1004.2	1180	3.783	1.025	1.2143	456.4	0.57379	39.191	0.065877	vapor
940	0.2	1.1258	0.88826	1014.5	1192.1	3.796	1.028	1.2174	458.74	0.55159	39.492	0.066559	vapor
950	0.2	1.1139	0.89772	1024.8	1204.3	3.8089	1.031	1.2204	461.08	0.53005	39.792	0.067238	vapor
960	0.2	1.1023	0.90717	1035.1	1216.5	3.8217	1.034	1.2233	463.4	0.50914	40.09	0.067913	vapor
970	0.2	1.091	0.91663	1045.5	1228.8	3.8344	1.0369	1.2262	465.7	0.48883	40.386	0.068586	vapor
980	0.2	1.0798	0.92608	1055.9	1241.1	3.847	1.0397	1.229	468	0.46911	40.68	0.069255	vapor
990	0.2	1.0689	0.93554	1066.3	1253.4	3.8595	1.0425	1.2318	470.29	0.44994	40.973	0.069921	vapor
1000	0.2	1.0582	0.94499	1076.7	1265.7	3.8719	1.0452	1.2345	472.56	0.43131	41.264	0.070584	vapor
1010	0.2	1.0477	0.95445	1087.2	1278.1	3.8842	1.0479	1.2372	474.83	0.4132	41.553	0.071245	vapor
1020	0.2	1.0374	0.9639	1097.7	1290.4	3.8964	1.0506	1.2399	477.08	0.39558	41.841	0.071902	vapor

1030	0.2	1.0274	0.97336	1108.2	1302.9	3.9085	1.0532	1.2425	479.32	0.37843	42.127	0.072556	vapor
1040	0.2	1.0175	0.98281	1118.7	1315.3	3.9205	1.0558	1.245	481.56	0.36174	42.411	0.073207	vapor
1050	0.2	1.0078	0.99227	1129.3	1327.8	3.9324	1.0583	1.2475	483.78	0.34548	42.694	0.073856	vapor
1060	0.2	0.99828	1.0017	1139.9	1340.2	3.9442	1.0607	1.25	485.99	0.32966	42.975	0.074501	vapor
1070	0.2	0.98895	1.0112	1150.5	1352.8	3.956	1.0632	1.2524	488.19	0.31423	43.255	0.075144	vapor
1080	0.2	0.97979	1.0206	1161.2	1365.3	3.9677	1.0656	1.2548	490.39	0.29921	43.533	0.075783	vapor
1090	0.2	0.97079	1.0301	1171.8	1377.9	3.9792	1.0679	1.2571	492.57	0.28456	43.81	0.07642	vapor
1100	0.2	0.96197	1.0395	1182.5	1390.4	3.9907	1.0702	1.2594	494.74	0.27027	44.086	0.077054	vapor

Table 25. Isobaric CO_2 Properties at 1 MPa. Source [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (Pa*s)	Therm. Cond. (W/m*K)	Phase
220	1	1167	0.00086	85.976	86.832	0.5506	0.97034	1.9589	953.55	-0.13348	0.000243	0.17649	liquid
230	1	1129	0.00089	105.71	106.59	0.6384	0.9568	1.9959	879.82	-0.08765	0.000204	0.16338	liquid
233.03	1	1116.9	0.0009	111.76	112.66	0.6646	0.95303	2.0111	857.18	-0.070581	0.000194	0.15945	liquid
233.03	1	26.006	0.03845	396.84	435.3	2.0491	0.68026	1.0322	223.5	21.542	1.19E-05	0.012528	vapor
240	1	24.857	0.04023	402.14	442.37	2.0791	0.67332	0.99915	228.46	19.772	1.22E-05	0.012944	vapor
250	1	23.435	0.04267	409.51	452.18	2.1191	0.66716	0.96579	235.08	17.606	1.27E-05	0.013584	vapor
260	1	22.215	0.04502	416.71	461.73	2.1566	0.66557	0.94495	241.19	15.791	1.32E-05	0.014264	vapor
270	1	21.147	0.04729	423.82	471.11	2.192	0.66718	0.93235	246.91	14.254	1.37E-05	0.014975	vapor
280	1	20.199	0.04951	430.89	480.39	2.2257	0.67092	0.92518	252.33	12.936	1.42E-05	0.015713	vapor
290	1	19.349	0.05168	437.94	489.63	2.2581	0.67607	0.92172	257.48	11.796	1.46E-05	0.016472	vapor
300	1	18.579	0.05382	445.01	498.84	2.2894	0.68217	0.92089	262.43	10.802	1.51E-05	0.017248	vapor
310	1	17.878	0.05594	452.12	508.05	2.3196	0.6889	0.92192	267.2	9.9291	1.56E-05	0.018039	vapor
320	1	17.234	0.05802	459.26	517.28	2.3489	0.69605	0.92433	271.8	9.159	1.61E-05	0.018841	vapor
330	1	16.641	0.06009	466.45	526.54	2.3774	0.70349	0.92777	276.28	8.4756	1.65E-05	0.019652	vapor
340	1	16.092	0.06214	473.7	535.84	2.4051	0.71112	0.932	280.62	7.8662	1.70E-05	0.020471	vapor
350	1	15.581	0.06418	481	545.18	2.4322	0.71885	0.93681	284.86	7.3204	1.75E-05	0.021295	vapor
360	1	15.105	0.0662	488.37	554.58	2.4587	0.72663	0.94206	289	6.8295	1.79E-05	0.022123	vapor
370	1	14.659	0.06822	495.81	564.02	2.4846	0.73442	0.94763	293.05	6.3863	1.84E-05	0.022955	vapor
380	1	14.241	0.07022	503.31	573.53	2.5099	0.74217	0.95345	297.02	5.9847	1.89E-05	0.023788	vapor
390	1	13.848	0.07221	510.88	583.09	2.5348	0.74988	0.95944	300.91	5.6195	1.93E-05	0.024623	vapor
400	1	13.477	0.0742	518.52	592.72	2.5591	0.75751	0.96555	304.72	5.2864	1.98E-05	0.025458	vapor
410	1	13.127	0.07618	526.23	602.41	2.583	0.76505	0.97174	308.47	4.9817	2.02E-05	0.026293	vapor
420	1	12.796	0.07815	534	612.15	2.6065	0.77251	0.97798	312.16	4.702	2.06E-05	0.027127	vapor
430	1	12.482	0.08012	541.85	621.97	2.6296	0.77986	0.98423	315.79	4.4447	2.11E-05	0.027959	vapor
440	1	12.183	0.08208	549.76	631.84	2.6523	0.7871	0.99049	319.37	4.2074	2.15E-05	0.028791	vapor
450	1	11.899	0.08404	557.74	641.78	2.6746	0.79424	0.99673	322.89	3.988	2.20E-05	0.02962	vapor
460	1	11.629	0.08599	565.78	651.77	2.6966	0.80126	1.0029	326.37	3.7846	2.24E-05	0.030448	vapor
470	1	11.371	0.08794	573.89	661.83	2.7183	0.80817	1.0091	329.79	3.5957	2.28E-05	0.031274	vapor
480	1	11.125	0.08989	582.07	671.96	2.7396	0.81497	1.0152	333.18	3.4198	2.32E-05	0.032097	vapor
490	1	10.889	0.09183	590.31	682.14	2.7606	0.82166	1.0213	336.52	3.2559	2.36E-05	0.032917	vapor
500	1	10.664	0.09377	598.61	692.38	2.7813	0.82823	1.0273	339.81	3.1027	2.41E-05	0.033735	vapor
510	1	10.448	0.09571	606.97	702.68	2.8017	0.83469	1.0332	343.07	2.9593	2.45E-05	0.034551	vapor
520	1	10.241	0.09765	615.4	713.05	2.8218	0.84104	1.0391	346.3	2.8248	2.49E-05	0.035363	vapor
530	1	10.042	0.09958	623.89	723.47	2.8416	0.84729	1.0449	349.48	2.6986	2.53E-05	0.036173	vapor
540	1	9.8512	0.10151	632.43	733.94	2.8612	0.85342	1.0506	352.64	2.5798	2.57E-05	0.036979	vapor
550	1	9.6675	0.10344	641.04	744.48	2.8805	0.85946	1.0563	355.76	2.468	2.61E-05	0.037783	vapor
560	1	9.4907	0.10537	649.7	755.07	2.8996	0.86538	1.0618	358.84	2.3625	2.65E-05	0.038584	vapor
570	1	9.3203	0.10729	658.42	765.71	2.9185	0.87121	1.0673	361.9	2.2629	2.69E-05	0.039381	vapor
580	1	9.1562	0.10922	667.2	776.41	2.9371	0.87693	1.0727	364.93	2.1687	2.73E-05	0.040176	vapor

590	1	8.9978	0.11114	676.03	787.17	2.9555	0.88256	1.078	367.93	2.0795	2.77E-05	0.040968	vapor
600	1	8.8449	0.11306	684.91	797.97	2.9736	0.88808	1.0833	370.9	1.9949	2.80E-05	0.041756	vapor
610	1	8.6972	0.11498	693.85	808.83	2.9916	0.89352	1.0885	373.84	1.9147	2.84E-05	0.042541	vapor
620	1	8.5545	0.1169	702.85	819.74	3.0093	0.89885	1.0936	376.76	1.8384	2.88E-05	0.043323	vapor
630	1	8.4164	0.11881	711.89	830.7	3.0268	0.9041	1.0986	379.65	1.7659	2.92E-05	0.044102	vapor
640	1	8.2829	0.12073	720.98	841.71	3.0442	0.90925	1.1035	382.51	1.6969	2.95E-05	0.044878	vapor
650	1	8.1535	0.12265	730.13	852.77	3.0613	0.91432	1.1084	385.36	1.6311	2.99E-05	0.045651	vapor
660	1	8.0282	0.12456	739.32	863.88	3.0783	0.9193	1.1132	388.18	1.5684	3.03E-05	0.046421	vapor
670	1	7.9068	0.12647	748.56	875.04	3.0951	0.92419	1.1179	390.98	1.5085	3.06E-05	0.047187	vapor
680	1	7.789	0.12839	757.85	886.24	3.1117	0.92899	1.1225	393.75	1.4513	3.10E-05	0.04795	vapor
690	1	7.6747	0.1303	767.19	897.49	3.1281	0.93371	1.1271	396.51	1.3966	3.14E-05	0.04871	vapor
700	1	7.5638	0.13221	776.57	908.78	3.1443	0.93835	1.1315	399.24	1.3443	3.17E-05	0.049467	vapor
710	1	7.4561	0.13412	786	920.12	3.1604	0.94291	1.136	401.95	1.2941	3.21E-05	0.050221	vapor
720	1	7.3514	0.13603	795.47	931.5	3.1763	0.94739	1.1403	404.65	1.2461	3.24E-05	0.050971	vapor
730	1	7.2497	0.13794	804.99	942.92	3.1921	0.95179	1.1446	407.32	1.2	3.28E-05	0.051718	vapor
740	1	7.1508	0.13984	814.55	954.39	3.2077	0.95612	1.1488	409.97	1.1557	3.31E-05	0.052462	vapor
750	1	7.0546	0.14175	824.15	965.9	3.2231	0.96037	1.1529	412.61	1.1132	3.34E-05	0.053203	vapor
760	1	6.9609	0.14366	833.79	977.45	3.2384	0.96454	1.157	415.23	1.0724	3.38E-05	0.053941	vapor
770	1	6.8698	0.14557	843.47	989.04	3.2536	0.96864	1.161	417.83	1.0331	3.41E-05	0.054675	vapor
780	1	6.781	0.14747	853.2	1000.7	3.2686	0.97268	1.1649	420.42	0.99533	3.45E-05	0.055406	vapor
790	1	6.6945	0.14938	862.96	1012.3	3.2835	0.97663	1.1687	422.99	0.95894	3.48E-05	0.056134	vapor
800	1	6.6102	0.15128	872.76	1024	3.2982	0.98052	1.1725	425.54	0.92388	3.51E-05	0.056859	vapor
810	1	6.528	0.15319	882.6	1035.8	3.3128	0.98435	1.1763	428.07	0.89009	3.54E-05	0.057581	vapor
820	1	6.4479	0.15509	892.48	1047.6	3.3272	0.9881	1.1799	430.59	0.85749	3.58E-05	0.058299	vapor
830	1	6.3697	0.15699	902.39	1059.4	3.3416	0.99179	1.1835	433.1	0.82603	3.61E-05	0.059014	vapor
840	1	6.2934	0.1589	912.34	1071.2	3.3557	0.99542	1.1871	435.59	0.79566	3.64E-05	0.059726	vapor
850	1	6.219	0.1608	922.33	1083.1	3.3698	0.99898	1.1906	438.06	0.76632	3.67E-05	0.060435	vapor
860	1	6.1462	0.1627	932.35	1095	3.3838	1.0025	1.194	440.52	0.73797	3.70E-05	0.061141	vapor
870	1	6.0752	0.1646	942.4	1107	3.3976	1.0059	1.1974	442.97	0.71055	3.74E-05	0.061843	vapor
880	1	6.0058	0.1665	952.49	1119	3.4113	1.0093	1.2007	445.4	0.68402	3.77E-05	0.062542	vapor
890	1	5.938	0.16841	962.61	1131	3.4249	1.0126	1.2039	447.82	0.65835	3.80E-05	0.063238	vapor
900	1	5.8718	0.17031	972.77	1143.1	3.4383	1.0159	1.2071	450.22	0.63349	3.83E-05	0.063931	vapor
910	1	5.807	0.17221	982.95	1155.2	3.4517	1.0191	1.2103	452.61	0.60941	3.86E-05	0.064621	vapor
920	1	5.7436	0.17411	993.17	1167.3	3.4649	1.0222	1.2134	454.99	0.58607	3.89E-05	0.065308	vapor
930	1	5.6816	0.17601	1003.4	1179.4	3.4781	1.0253	1.2164	457.36	0.56344	3.92E-05	0.065991	vapor
940	1	5.6209	0.17791	1013.7	1191.6	3.4911	1.0284	1.2194	459.71	0.5415	3.95E-05	0.066672	vapor
950	1	5.5615	0.17981	1024	1203.8	3.504	1.0313	1.2223	462.06	0.5202	3.98E-05	0.067349	vapor
960	1	5.5034	0.18171	1034.3	1216.1	3.5168	1.0343	1.2252	464.39	0.49954	4.01E-05	0.068023	vapor
970	1	5.4465	0.18361	1044.7	1228.3	3.5295	1.0372	1.228	466.7	0.47947	4.04E-05	0.068695	vapor
980	1	5.3907	0.1855	1055.1	1240.6	3.5422	1.04	1.2308	469.01	0.45997	4.07E-05	0.069363	vapor
990	1	5.3361	0.1874	1065.5	1252.9	3.5547	1.0428	1.2336	471.3	0.44103	4.10E-05	0.070028	vapor
1000	1	5.2826	0.1893	1076	1265.3	3.5671	1.0455	1.2362	473.59	0.42261	4.13E-05	0.07069	vapor

1010	1	5.2301	0.1912	1086.5	1277.7	3.5794	1.0482	1.2389	475.86	0.4047	4.16E-05	0.071349	vapor
1020	1	5.1787	0.1931	1097	1290.1	3.5916	1.0508	1.2415	478.12	0.38728	4.19E-05	0.072005	vapor
1030	1	5.1283	0.19499	1107.5	1302.5	3.6037	1.0534	1.2441	480.37	0.37033	4.21E-05	0.072659	vapor
1040	1	5.0789	0.19689	1118	1314.9	3.6158	1.056	1.2466	482.61	0.35383	4.24E-05	0.073309	vapor
1050	1	5.0304	0.19879	1128.6	1327.4	3.6277	1.0585	1.249	484.84	0.33777	4.27E-05	0.073956	vapor
1060	1	4.9829	0.20069	1139.2	1339.9	3.6396	1.061	1.2515	487.06	0.32212	4.30E-05	0.074601	vapor
1070	1	4.9362	0.20258	1149.9	1352.4	3.6513	1.0634	1.2539	489.27	0.30688	4.33E-05	0.075242	vapor
1080	1	4.8904	0.20448	1160.5	1365	3.663	1.0658	1.2562	491.47	0.29202	4.36E-05	0.075881	vapor

Table 26. Isobaric CO_2 Properties at 2 MPa. Source: [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (Pa*s)	Therm. Cond. (W/m*K)	Phase
220	2	1169.2	0.00086	85.387	87.097	0.5479	0.9716	1.9517	959.33	-0.13757	0.000245	0.17732	liquid
230	2	1131.6	0.00088	105	106.77	0.6353	0.95796	1.9858	886.59	-0.093624	0.000206	0.16431	liquid
240	2	1091.2	0.00092	125.05	126.88	0.7209	0.9461	2.0404	812.17	-0.032941	0.000174	0.1515	liquid
250	2	1046.9	0.00096	145.77	147.68	0.8058	0.9366	2.1271	733.93	0.053968	1.47E-04	0.13873	liquid
253.65	2	1029.4	0.00097	153.58	155.52	0.8369	0.93409	2.171	703.64	0.095569	1.38E-04	0.13404	liquid
253.65	2	52.54	0.01903	398.79	436.85	1.9461	0.76254	1.2983	220.27	17.353	1.32E-05	0.015173	vapor
260	2	49.914	0.02004	404.74	444.81	1.9771	0.74331	1.213	226.07	16.097	1.34E-05	0.015424	vapor
270	2	46.533	0.02149	413.5	456.48	2.0211	0.72439	1.1276	234.21	14.437	1.39E-05	0.015944	vapor
280	2	43.772	0.02285	421.78	467.47	2.0611	0.71503	1.0758	241.45	13.049	1.44E-05	0.016556	vapor
290	2	41.438	0.02413	429.79	478.05	2.0982	0.71135	1.0425	248.05	11.864	1.48E-05	0.017225	vapor
300	2	39.42	0.02537	437.62	488.36	2.1332	0.71116	1.0206	254.15	10.84	1.53E-05	0.017934	vapor
310	2	37.645	0.02656	445.36	498.49	2.1664	0.71317	1.0059	259.89	9.9473	1.58E-05	0.018671	vapor
320	2	36.063	0.02773	453.04	508.5	2.1982	0.71664	0.99621	265.31	9.1625	1.62E-05	0.019429	vapor
330	2	34.639	0.02887	460.69	518.42	2.2287	0.72117	0.99008	270.49	8.4682	1.67E-05	0.020204	vapor
340	2	33.346	0.02999	468.33	528.31	2.2582	0.72645	0.98659	275.45	7.8504	1.71E-05	0.020992	vapor
350	2	32.165	0.03109	475.98	538.16	2.2868	0.73225	0.98506	280.22	7.2981	1.76E-05	0.021789	vapor
360	2	31.079	0.03218	483.66	548.01	2.3145	0.73841	0.98503	284.83	6.8022	1.81E-05	0.022594	vapor
370	2	30.075	0.03325	491.37	557.87	2.3415	0.74484	0.98616	289.3	6.3552	1.85E-05	0.023405	vapor
380	2	29.143	0.03431	499.11	567.74	2.3679	0.75144	0.98819	293.64	5.9506	1.90E-05	0.024219	vapor
390	2	28.276	0.03537	506.9	577.63	2.3936	0.75815	0.99093	297.87	5.5832	1.94E-05	0.025037	vapor
400	2	27.464	0.03641	514.74	587.56	2.4187	0.76494	0.99423	301.99	5.2485	1.99E-05	0.025856	vapor
410	2	26.704	0.03745	522.62	597.52	2.4433	0.77175	0.99798	306.02	4.9427	2.03E-05	0.026677	vapor
420	2	25.989	0.03848	530.56	607.52	2.4674	0.77856	1.0021	309.96	4.6623	2.07E-05	0.027498	vapor
430	2	25.314	0.0395	538.56	617.56	2.491	0.78535	1.0064	313.83	4.4046	2.12E-05	0.028318	vapor
440	2	24.678	0.04052	546.6	627.65	2.5142	0.79211	1.011	317.61	4.1671	2.16E-05	0.029138	vapor
450	2	24.075	0.04154	554.71	637.78	2.537	0.79881	1.0158	321.33	3.9477	2.20E-05	0.029955	vapor
460	2	23.504	0.04255	562.87	647.96	2.5594	0.80545	1.0207	324.99	3.7446	2.25E-05	0.030774	vapor
470	2	22.961	0.04355	571.09	658.2	2.5814	0.81202	1.0256	328.58	3.556	2.29E-05	0.031591	vapor
480	2	22.444	0.04456	579.37	668.48	2.603	0.81852	1.0307	332.12	3.3807	2.33E-05	0.032406	vapor
490	2	21.952	0.04556	587.7	678.81	2.6243	0.82493	1.0358	335.6	3.2173	2.37E-05	0.033219	vapor
500	2	21.482	0.04655	596.09	689.19	2.6453	0.83126	1.0409	339.03	3.0647	2.41E-05	0.03403	vapor
510	2	21.033	0.04754	604.54	699.63	2.666	0.8375	1.046	342.42	2.922	2.45E-05	0.034838	vapor
520	2	20.604	0.04854	613.04	710.11	2.6863	0.84365	1.0511	345.76	2.7883	2.50E-05	0.035644	vapor
530	2	20.192	0.04952	621.6	720.65	2.7064	0.84972	1.0563	349.05	2.6628	2.54E-05	0.036447	vapor
540	2	19.798	0.05051	630.22	731.24	2.7262	0.85569	1.0614	352.31	2.5449	2.58E-05	0.037248	vapor
550	2	19.42	0.0515	638.89	741.88	2.7457	0.86157	1.0664	355.52	2.4338	2.62E-05	0.038046	vapor
560	2	19.056	0.05248	647.61	752.57	2.765	0.86737	1.0715	358.7	2.3292	2.65E-05	0.038841	vapor
570	2	18.706	0.05346	656.39	763.31	2.784	0.87307	1.0765	361.84	2.2303	2.69E-05	0.039634	vapor
580	2	18.37	0.05444	665.22	774.1	2.8027	0.87868	1.0814	364.94	2.1369	2.73E-05	0.040423	vapor

590	2	18.046	0.05542	674.1	784.93	2.8213	0.8842	1.0863	368.01	2.0485	2.77E-05	0.04121	vapor
600	2	17.733	0.05639	683.04	795.82	2.8396	0.88964	1.0912	371.05	1.9647	2.81E-05	0.041994	vapor
610	2	17.432	0.05737	692.03	806.76	2.8576	0.89498	1.096	374.06	1.8853	2.85E-05	0.042775	vapor
620	2	17.141	0.05834	701.06	817.74	2.8755	0.90024	1.1008	377.04	1.8098	2.88E-05	0.043552	vapor
630	2	16.86	0.05931	710.15	828.77	2.8932	0.90541	1.1055	379.99	1.738	2.92E-05	0.044327	vapor
640	2	16.588	0.06028	719.28	839.85	2.9106	0.9105	1.1101	382.92	1.6697	2.96E-05	0.045099	vapor
650	2	16.325	0.06125	728.47	850.98	2.9278	0.9155	1.1147	385.81	1.6047	3.00E-05	0.045868	vapor
660	2	16.071	0.06222	737.7	862.15	2.9449	0.92042	1.1192	388.68	1.5427	3.03E-05	0.046634	vapor
670	2	15.825	0.06319	746.98	873.36	2.9618	0.92525	1.1237	391.53	1.4835	3.07E-05	0.047397	vapor
680	2	15.586	0.06416	756.3	884.62	2.9784	0.93001	1.1281	394.35	1.4269	3.10E-05	0.048157	vapor
690	2	15.355	0.06513	765.67	895.92	2.9949	0.93468	1.1325	397.14	1.3729	3.14E-05	0.048913	vapor
700	2	15.13	0.06609	775.08	907.27	3.0113	0.93928	1.1367	399.92	1.3211	3.18E-05	0.049667	vapor
710	2	14.913	0.06706	784.54	918.66	3.0274	0.9438	1.141	402.67	1.2716	3.21E-05	0.050418	vapor
720	2	14.701	0.06802	794.04	930.09	3.0434	0.94824	1.1451	405.4	1.2242	3.25E-05	0.051165	vapor
730	2	14.496	0.06899	803.59	941.56	3.0592	0.9526	1.1492	408.11	1.1786	3.28E-05	0.051909	vapor
740	2	14.296	0.06995	813.17	953.07	3.0749	0.9569	1.1533	410.8	1.135	3.31E-05	0.052651	vapor
750	2	14.102	0.07091	822.8	964.62	3.0904	0.96111	1.1572	413.46	1.093	3.35E-05	0.053389	vapor
760	2	13.913	0.07187	832.47	976.22	3.1058	0.96526	1.1611	416.11	1.0527	3.38E-05	0.054124	vapor
770	2	13.73	0.07284	842.18	987.85	3.121	0.96933	1.165	418.74	1.014	3.42E-05	0.054855	vapor
780	2	13.551	0.0738	851.92	999.52	3.136	0.97334	1.1688	421.35	0.97669	3.45E-05	0.055584	vapor
790	2	13.377	0.07476	861.71	1011.2	3.1509	0.97727	1.1725	423.95	0.94079	3.48E-05	0.05631	vapor
800	2	13.207	0.07572	871.53	1023	3.1657	0.98114	1.1762	426.52	0.9062	3.52E-05	0.057032	vapor
810	2	13.042	0.07668	881.39	1034.7	3.1803	0.98494	1.1798	429.08	0.87286	3.55E-05	0.057751	vapor
820	2	12.881	0.07764	891.29	1046.6	3.1948	0.98867	1.1834	431.63	0.84072	3.58E-05	0.058467	vapor
830	2	12.724	0.0786	901.23	1058.4	3.2092	0.99234	1.1869	434.15	0.80969	3.61E-05	0.05918	vapor
840	2	12.57	0.07955	911.2	1070.3	3.2234	0.99595	1.1903	436.66	0.77974	3.64E-05	0.05989	vapor
850	2	12.421	0.08051	921.2	1082.2	3.2375	0.99949	1.1937	439.16	0.75081	3.68E-05	0.060597	vapor
860	2	12.275	0.08147	931.24	1094.2	3.2515	1.003	1.1971	441.63	0.72285	3.71E-05	0.0613	vapor
870	2	12.132	0.08243	941.31	1106.2	3.2654	1.0064	1.2003	444.1	0.69581	3.74E-05	0.062001	vapor
880	2	11.993	0.08338	951.42	1118.2	3.2791	1.0098	1.2036	446.55	0.66966	3.77E-05	0.062698	vapor
890	2	11.857	0.08434	961.56	1130.2	3.2927	1.0131	1.2067	448.98	0.64435	3.80E-05	0.063392	vapor
900	2	11.724	0.0853	971.73	1142.3	3.3062	1.0163	1.2099	451.4	0.61984	3.83E-05	0.064083	vapor
910	2	11.594	0.08625	981.93	1154.4	3.3196	1.0195	1.2129	453.81	0.5961	3.86E-05	0.064771	vapor
920	2	11.467	0.08721	992.16	1166.6	3.3329	1.0226	1.2159	456.2	0.5731	3.89E-05	0.065456	vapor
930	2	11.343	0.08816	1002.4	1178.7	3.3461	1.0257	1.2189	458.58	0.55079	3.92E-05	0.066138	vapor
940	2	11.221	0.08912	1012.7	1191	3.3591	1.0287	1.2218	460.95	0.52916	3.95E-05	0.066817	vapor
950	2	11.102	0.09007	1023	1203.2	3.3721	1.0317	1.2247	463.3	0.50817	3.98E-05	0.067493	vapor
960	2	10.986	0.09103	1033.4	1215.4	3.3849	1.0346	1.2275	465.64	0.48779	4.01E-05	0.068165	vapor
970	2	10.872	0.09198	1043.8	1227.7	3.3976	1.0375	1.2303	467.97	0.46801	4.04E-05	0.068835	vapor
980	2	10.76	0.09294	1054.2	1240.1	3.4103	1.0403	1.233	470.29	0.44879	4.07E-05	0.069502	vapor
990	2	10.651	0.09389	1064.6	1252.4	3.4228	1.0431	1.2357	472.6	0.43012	4.10E-05	0.070165	vapor
1000	2	10.544	0.09484	1075.1	1264.8	3.4352	1.0459	1.2384	474.89	0.41196	4.13E-05	0.070826	vapor

1010	2	10.439	0.0958	1085.6	1277.2	3.4476	1.0485	1.241	477.17	0.39431	4.16E-05	0.071484	vapor
1020	2	10.336	0.09675	1096.1	1289.6	3.4598	1.0512	1.2435	479.44	0.37714	4.19E-05	0.072139	vapor
1030	2	10.235	0.0977	1106.6	1302	3.4719	1.0538	1.246	481.7	0.36043	4.22E-05	0.07279	vapor
1040	2	10.136	0.09866	1117.2	1314.5	3.484	1.0563	1.2485	483.95	0.34417	4.25E-05	0.073439	vapor
1050	2	10.039	0.09961	1127.8	1327	3.496	1.0588	1.2509	486.19	0.32833	4.27E-05	0.074085	vapor
1060	2	9.9443	0.10056	1138.4	1339.5	3.5078	1.0613	1.2533	488.41	0.31291	4.30E-05	0.074728	vapor
1070	2	9.851	0.10151	1149	1352.1	3.5196	1.0637	1.2557	490.63	0.29788	4.33E-05	0.075369	vapor
1080	2	9.7595	0.10246	1159.7	1364.6	3.5313	1.0661	1.258	492.84	0.28323	4.36E-05	0.076006	vapor

Table 27. Isobaric CO_2 Properties at 4 MPa. Source: [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (Pa*s)	Therm. Cond. (W/m*K)	Phase
220	4	1173.5	0.00085	84.239	87.648	0.5426	0.97402	1.9384	970.66	-0.14533	0.000249	0.17895	liquid
230	4	1136.8	0.00088	103.65	107.16	0.6294	0.9602	1.9673	899.79	-0.10481	0.00021	0.16612	liquid
240	4	1097.6	0.00091	123.41	127.05	0.714	0.9481	2.0134	827.8	-0.049719	0.000178	0.15354	liquid
250	4	1055	0.00095	143.72	147.52	0.7975	0.93814	2.0849	753.1	0.027229	1.51E-04	0.14109	liquid
260	4	1007.5	0.00099	164.92	168.89	0.8813	0.93199	2.1986	672.67	0.14008	1.28E-04	0.12857	liquid
270	4	952.1	0.00105	187.56	191.76	0.9677	0.93573	2.3972	580.72	0.32044	1.07E-04	0.11566	liquid
278.45	4	894.05	0.00112	208.8	213.27	1.0461	0.95655	2.7401	486.42	0.59275	9.03E-05	0.10394	liquid
278.45	4	115.74	0.00864	392.69	427.25	1.8145	0.91069	2.1642	208.78	13.423	1.54E-05	0.021735	vapor
280	4	113.08	0.00884	395.12	430.49	1.8261	0.89131	2.0294	211.36	13.204	1.54E-05	0.021389	vapor
290	4	100.47	0.00995	408.33	448.14	1.8881	0.82129	1.578	224.72	11.918	1.57E-05	0.020474	vapor
300	4	91.965	0.01087	419.35	462.85	1.938	0.79011	1.385	235.04	10.832	1.60E-05	0.020454	vapor
310	4	85.508	0.0117	429.34	476.11	1.9815	0.77402	1.2773	243.77	9.9017	1.64E-05	0.020765	vapor
320	4	80.306	0.01245	438.71	488.52	2.0209	0.76551	1.2092	251.49	9.0944	1.68E-05	0.02124	vapor
330	4	75.958	0.01317	447.71	500.37	2.0574	0.76156	1.1633	258.49	8.386	1.72E-05	0.021812	vapor
340	4	72.231	0.01384	456.46	511.84	2.0916	0.76054	1.1312	264.95	7.7593	1.76E-05	0.022446	vapor
350	4	68.976	0.0145	465.03	523.03	2.124	0.76145	1.108	270.98	7.2015	1.80E-05	0.023122	vapor
360	4	66.093	0.01513	473.5	534.02	2.155	0.76371	1.0912	276.67	6.7024	1.84E-05	0.023829	vapor
370	4	63.509	0.01575	481.88	544.86	2.1847	0.76695	1.0789	282.06	6.2538	1.89E-05	0.024557	vapor
380	4	61.173	0.01635	490.22	555.61	2.2134	0.77091	1.07	287.22	5.8488	1.93E-05	0.025302	vapor
390	4	59.045	0.01694	498.53	566.27	2.2411	0.77542	1.0637	292.17	5.4817	1.97E-05	0.02606	vapor
400	4	57.094	0.01752	506.83	576.89	2.268	0.78032	1.0595	296.93	5.1478	2.02E-05	0.026826	vapor
410	4	55.294	0.01809	515.13	587.47	2.2941	0.78553	1.0569	301.53	4.8432	2.06E-05	0.0276	vapor
420	4	53.627	0.01865	523.44	598.03	2.3195	0.79097	1.0555	305.99	4.5644	2.10E-05	0.028379	vapor
430	4	52.076	0.0192	531.77	608.58	2.3444	0.79657	1.0552	310.31	4.3086	2.14E-05	0.029162	vapor
440	4	50.628	0.01975	540.13	619.13	2.3686	0.80228	1.0556	314.52	4.073	2.19E-05	0.029946	vapor
450	4	49.27	0.0203	548.51	629.7	2.3924	0.80808	1.0568	318.63	3.8557	2.23E-05	0.030726	vapor
460	4	47.995	0.02084	556.93	640.27	2.4156	0.81391	1.0585	322.64	3.6547	2.27E-05	0.03152	vapor
470	4	46.794	0.02137	565.39	650.87	2.4384	0.81978	1.0607	326.55	3.4684	2.31E-05	0.032313	vapor
480	4	45.659	0.0219	573.88	661.49	2.4607	0.82564	1.0633	330.39	3.2953	2.35E-05	0.033107	vapor
490	4	44.585	0.02243	582.42	672.13	2.4827	0.8315	1.0661	334.15	3.1341	2.39E-05	0.033899	vapor
500	4	43.566	0.02295	591	682.81	2.5043	0.83733	1.0692	337.84	2.9838	2.43E-05	0.034691	vapor
510	4	42.599	0.02348	599.62	693.52	2.5255	0.84312	1.0726	341.46	2.8433	2.47E-05	0.035481	vapor
520	4	41.678	0.02399	608.29	704.26	2.5463	0.84887	1.0761	345.02	2.7118	2.51E-05	0.03627	vapor
530	4	40.8	0.02451	617	715.04	2.5669	0.85457	1.0797	348.52	2.5885	2.55E-05	0.037057	vapor
540	4	39.961	0.02502	625.76	725.86	2.5871	0.86021	1.0834	351.96	2.4726	2.59E-05	0.037843	vapor
550	4	39.16	0.02554	634.57	736.71	2.607	0.8658	1.0873	355.36	2.3637	2.63E-05	0.038626	vapor
560	4	38.393	0.02605	643.42	747.6	2.6266	0.87132	1.0912	358.7	2.261	2.67E-05	0.039408	vapor
570	4	37.658	0.02656	652.32	758.53	2.646	0.87677	1.0951	362	2.1641	2.71E-05	0.040187	vapor

580	4	36.953	0.02706	661.26	769.51	2.6651	0.88216	1.0992	365.25	2.0726	2.75E-05	0.040965	vapor
590	4	36.276	0.02757	670.25	780.52	2.6839	0.88748	1.1032	368.46	1.9861	2.79E-05	0.04174	vapor
600	4	35.625	0.02807	679.29	791.57	2.7025	0.89272	1.1072	371.63	1.9041	2.82E-05	0.042512	vapor
610	4	34.999	0.02857	688.37	802.66	2.7208	0.89789	1.1113	374.76	1.8264	2.86E-05	0.043282	vapor
620	4	34.396	0.02907	697.5	813.8	2.7389	0.90299	1.1153	377.85	1.7526	2.90E-05	0.04405	vapor
630	4	33.814	0.02957	706.68	824.97	2.7568	0.90801	1.1194	380.91	1.6825	2.93E-05	0.044815	vapor
640	4	33.254	0.03007	715.9	836.18	2.7744	0.91296	1.1234	383.94	1.6158	2.97E-05	0.045577	vapor
650	4	32.712	0.03057	725.16	847.44	2.7919	0.91784	1.1274	386.93	1.5523	3.01E-05	0.046337	vapor
660	4	32.189	0.03107	734.47	858.73	2.8091	0.92264	1.1314	389.89	1.4918	3.04E-05	0.047094	vapor
670	4	31.683	0.03156	743.82	870.07	2.8262	0.92737	1.1354	392.82	1.434	3.08E-05	0.047849	vapor
680	4	31.194	0.03206	753.21	881.44	2.843	0.93202	1.1393	395.73	1.3789	3.12E-05	0.048601	vapor
690	4	30.721	0.03255	762.65	892.85	2.8597	0.93661	1.1432	398.6	1.3262	3.15E-05	0.049349	vapor
700	4	30.262	0.03305	772.13	904.3	2.8762	0.94111	1.1471	401.45	1.2758	3.19E-05	0.050096	vapor
710	4	29.818	0.03354	781.64	915.79	2.8925	0.94555	1.1509	404.27	1.2275	3.22E-05	0.050839	vapor
720	4	29.387	0.03403	791.21	927.32	2.9086	0.94992	1.1547	407.07	1.1813	3.26E-05	0.051579	vapor
730	4	28.968	0.03452	800.81	938.89	2.9245	0.95421	1.1585	409.84	1.137	3.29E-05	0.052317	vapor
740	4	28.562	0.03501	810.45	950.49	2.9403	0.95844	1.1622	412.59	1.0944	3.32E-05	0.053052	vapor
750	4	28.168	0.0355	820.13	962.13	2.9559	0.96259	1.1658	415.31	1.0536	3.36E-05	0.053783	vapor
760	4	27.785	0.03599	829.85	973.81	2.9714	0.96668	1.1695	418.01	1.0144	3.39E-05	0.054512	vapor
770	4	27.413	0.03648	839.6	985.52	2.9867	0.9707	1.173	420.7	0.97667	3.43E-05	0.055238	vapor
780	4	27.051	0.03697	849.4	997.27	3.0019	0.97465	1.1766	423.36	0.94039	3.46E-05	0.055961	vapor
790	4	26.698	0.03746	859.23	1009.1	3.0169	0.97854	1.18	426	0.90547	3.49E-05	0.056681	vapor
800	4	26.355	0.03794	869.1	1020.9	3.0317	0.98236	1.1835	428.62	0.87183	3.52E-05	0.057398	vapor
810	4	26.021	0.03843	879	1032.7	3.0465	0.98611	1.1869	431.22	0.83941	3.56E-05	0.058112	vapor
820	4	25.696	0.03892	888.94	1044.6	3.0611	0.98981	1.1902	433.8	0.80814	3.59E-05	0.058823	vapor
830	4	25.379	0.0394	898.91	1056.5	3.0755	0.99344	1.1935	436.37	0.77798	3.62E-05	0.059531	vapor
840	4	25.07	0.03989	908.92	1068.5	3.0898	0.99701	1.1968	438.91	0.74886	3.65E-05	0.060236	vapor
850	4	24.769	0.04037	918.97	1080.5	3.104	1.0005	1.2	441.44	0.72073	3.68E-05	0.060938	vapor
860	4	24.475	0.04086	929.04	1092.5	3.1181	1.004	1.2031	443.96	0.69355	3.72E-05	0.061637	vapor
870	4	24.188	0.04134	939.15	1104.5	3.132	1.0074	1.2062	446.45	0.66727	3.75E-05	0.062333	vapor
880	4	23.908	0.04183	949.29	1116.6	3.1458	1.0107	1.2093	448.93	0.64185	3.78E-05	0.063026	vapor
890	4	23.634	0.04231	959.46	1128.7	3.1595	1.014	1.2123	451.4	0.61724	3.81E-05	0.063716	vapor
900	4	23.367	0.0428	969.66	1140.8	3.173	1.0172	1.2153	453.84	0.59343	3.84E-05	0.064403	vapor
910	4	23.106	0.04328	979.9	1153	3.1865	1.0204	1.2182	456.28	0.57035	3.87E-05	0.065087	vapor
920	4	22.851	0.04376	990.16	1165.2	3.1998	1.0235	1.2211	458.7	0.54799	3.90E-05	0.065768	vapor
930	4	22.602	0.04425	1000.5	1177.4	3.213	1.0265	1.2239	461.1	0.52632	3.93E-05	0.066446	vapor
940	4	22.358	0.04473	1010.8	1189.7	3.2261	1.0295	1.2267	463.49	0.50529	3.96E-05	0.067121	vapor
950	4	22.119	0.04521	1021.1	1202	3.2391	1.0325	1.2294	465.87	0.48489	3.99E-05	0.067794	vapor
960	4	21.886	0.04569	1031.5	1214.3	3.252	1.0354	1.2321	468.23	0.46509	4.02E-05	0.068463	vapor
970	4	21.658	0.04617	1041.9	1226.6	3.2648	1.0382	1.2348	470.58	0.44587	4.05E-05	0.069129	vapor
980	4	21.434	0.04666	1052.4	1239	3.2775	1.041	1.2374	472.91	0.42719	4.08E-05	0.069792	vapor
990	4	21.215	0.04714	1062.8	1251.4	3.29	1.0438	1.24	475.24	0.40904	4.11E-05	0.070453	vapor

1000	4	21.001	0.04762	1073.3	1263.8	3.3025	1.0465	1.2425	477.55	0.3914	4.14E-05	0.07111	vapor
1010	4	20.791	0.0481	1083.8	1276.2	3.3149	1.0492	1.245	479.85	0.37424	4.17E-05	0.071765	vapor
1020	4	20.585	0.04858	1094.4	1288.7	3.3272	1.0518	1.2475	482.13	0.35755	4.20E-05	0.072417	vapor
1030	4	20.383	0.04906	1104.9	1301.2	3.3394	1.0544	1.2499	484.41	0.34131	4.22E-05	0.073065	vapor
1040	4	20.186	0.04954	1115.5	1313.7	3.3514	1.0569	1.2523	486.67	0.3255	4.25E-05	0.073711	vapor
1050	4	19.992	0.05002	1126.1	1326.2	3.3634	1.0594	1.2546	488.92	0.31011	4.28E-05	0.074354	vapor
1060	4	19.802	0.0505	1136.8	1338.8	3.3753	1.0619	1.2569	491.16	0.29511	4.31E-05	0.074995	vapor
1070	4	19.616	0.05098	1147.4	1351.3	3.3872	1.0643	1.2592	493.39	0.2805	4.34E-05	0.075632	vapor
1080	4	19.433	0.05146	1158.1	1363.9	3.3989	1.0666	1.2615	495.61	0.26626	4.36E-05	0.076267	vapor

Table 28. Isobaric CO_2 Properties at 6 MPa. Source: [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (Pa*s)	Therm. Cond. (W/m*K)	Phase
220	6	1177.7	0.00085	83.129	88.224	0.5375	0.97632	1.926	981.74	-0.15257	0.000253	0.18054	liquid
230	6	1141.8	0.00088	102.34	107.59	0.6236	0.96231	1.9504	912.57	-0.1151	0.000214	0.16787	liquid
240	6	1103.6	0.00091	121.84	127.28	0.7074	0.95	1.9894	842.74	-0.064827	0.000182	0.15551	liquid
250	6	1062.6	0.00094	141.8	147.45	0.7897	0.93968	2.0491	771.04	0.0039525	1.55E-04	0.14333	liquid
260	6	1017.4	0.00098	162.47	168.36	0.8717	0.93233	2.1402	695.5	0.10139	1.32E-04	0.13121	liquid
270	6	966.16	0.00104	184.23	190.44	0.955	0.9307	2.2873	613.08	0.24777	1.12E-04	0.11892	liquid
280	6	904.68	0.00111	207.88	214.51	1.0425	0.93889	2.5598	519.2	0.49335	9.30E-05	0.10607	liquid
290	6	820.77	0.00122	235.7	243.01	1.1425	0.97135	3.2947	401.7	1.0219	7.44E-05	0.091741	liquid
295.13	6	751.03	0.00133	254.86	262.85	1.2102	1.0277	4.8386	314.35	1.7393	6.27E-05	0.083419	liquid
295.13	6	210.88	0.00474	374.87	403.32	1.6862	1.1086	5.5056	193.67	10.429	1.88E-05	0.037474	vapor
300	6	182.31	0.00549	389.25	422.16	1.7496	0.96413	2.9858	207.78	10.28	1.81E-05	0.029652	vapor
310	6	154.99	0.00645	407.03	445.74	1.827	0.8702	1.9705	224.44	9.5472	1.79E-05	0.025856	vapor
320	6	139.11	0.00719	420.41	463.54	1.8835	0.8317	1.6322	236.3	8.8102	1.79E-05	0.024836	vapor
330	6	127.87	0.00782	431.99	478.91	1.9308	0.81151	1.4588	246.04	8.1408	1.82E-05	0.024626	vapor
340	6	119.18	0.00839	442.59	492.93	1.9727	0.80035	1.3536	254.48	7.5403	1.84E-05	0.024779	vapor
350	6	112.12	0.00892	452.58	506.1	2.0109	0.7943	1.2837	262.05	7.0022	1.88E-05	0.02513	vapor
360	6	106.19	0.00942	462.17	518.68	2.0463	0.79142	1.2345	268.98	6.5189	1.91E-05	0.025601	vapor
370	6	101.1	0.00989	471.48	530.83	2.0796	0.7907	1.1988	275.41	6.0835	1.95E-05	0.02615	vapor
380	6	96.643	0.01035	480.6	542.68	2.1112	0.79152	1.1722	281.43	5.6897	1.98E-05	0.026754	vapor
390	6	92.694	0.01079	489.57	554.3	2.1414	0.79347	1.1521	287.12	5.3324	2.02E-05	0.027396	vapor
400	6	89.155	0.01122	498.44	565.74	2.1704	0.79627	1.1368	292.53	5.0072	2.06E-05	0.028067	vapor
410	6	85.954	0.01163	507.24	577.05	2.1983	0.79971	1.1252	297.71	4.7102	2.10E-05	0.02876	vapor
420	6	83.036	0.01204	516	588.25	2.2253	0.80365	1.1164	302.67	4.4382	2.14E-05	0.029469	vapor
430	6	80.36	0.01244	524.72	599.38	2.2515	0.80797	1.1099	307.45	4.1886	2.18E-05	0.030189	vapor
440	6	77.892	0.01284	533.43	610.46	2.2769	0.81258	1.1051	312.07	3.9587	2.22E-05	0.030918	vapor
450	6	75.605	0.01323	542.13	621.49	2.3017	0.81742	1.1018	316.54	3.7466	2.26E-05	0.031638	vapor
460	6	73.477	0.01361	550.84	632.5	2.3259	0.82242	1.0996	320.88	3.5504	2.30E-05	0.032396	vapor
470	6	71.488	0.01399	559.56	643.49	2.3496	0.82755	1.0984	325.1	3.3685	2.34E-05	0.033156	vapor
480	6	69.625	0.01436	568.29	654.47	2.3727	0.83277	1.098	329.21	3.1996	2.38E-05	0.033919	vapor
490	6	67.874	0.01473	577.05	665.45	2.3953	0.83805	1.0983	333.23	3.0423	2.42E-05	0.034684	vapor
500	6	66.223	0.0151	585.83	676.44	2.4175	0.84337	1.0991	337.15	2.8956	2.46E-05	0.035449	vapor
510	6	64.664	0.01547	594.65	687.43	2.4393	0.84871	1.1004	340.99	2.7585	2.50E-05	0.036215	vapor
520	6	63.187	0.01583	603.49	698.44	2.4607	0.85405	1.102	344.75	2.6302	2.54E-05	0.036982	vapor
530	6	61.786	0.01619	612.37	709.47	2.4817	0.85938	1.104	348.43	2.5099	2.58E-05	0.037748	vapor
540	6	60.454	0.01654	621.28	720.53	2.5024	0.8647	1.1062	352.05	2.3969	2.62E-05	0.038514	vapor
550	6	59.186	0.0169	630.22	731.6	2.5227	0.86998	1.1087	355.6	2.2907	2.65E-05	0.039279	vapor
560	6	57.977	0.01725	639.21	742.7	2.5427	0.87523	1.1114	359.1	2.1906	2.69E-05	0.040043	vapor
570	6	56.822	0.0176	648.24	753.83	2.5624	0.88044	1.1142	362.54	2.0962	2.73E-05	0.040806	vapor
580	6	55.717	0.01795	657.3	764.98	2.5818	0.8856	1.1172	365.92	2.007	2.77E-05	0.041568	vapor

590	6	54.66	0.0183	666.4	776.17	2.6009	0.89071	1.1203	369.25	1.9227	2.80E-05	0.042328	vapor
600	6	53.645	0.01864	675.54	787.39	2.6198	0.89577	1.1234	372.54	1.8428	2.84E-05	0.043086	vapor
610	6	52.672	0.01899	684.73	798.64	2.6383	0.90076	1.1267	375.78	1.7672	2.88E-05	0.043843	vapor
620	6	51.737	0.01933	693.95	809.92	2.6567	0.9057	1.13	378.97	1.6953	2.92E-05	0.044598	vapor
630	6	50.837	0.01967	703.22	821.24	2.6748	0.91058	1.1334	382.13	1.6271	2.95E-05	0.045351	vapor
640	6	49.971	0.02001	712.52	832.59	2.6927	0.9154	1.1367	385.25	1.5621	2.99E-05	0.046102	vapor
650	6	49.136	0.02035	721.87	843.98	2.7103	0.92015	1.1402	388.32	1.5003	3.02E-05	0.046851	vapor
660	6	48.331	0.02069	731.25	855.39	2.7278	0.92483	1.1436	391.37	1.4414	3.06E-05	0.047598	vapor
670	6	47.554	0.02103	740.68	866.85	2.745	0.92946	1.1471	394.37	1.3852	3.10E-05	0.048342	vapor
680	6	46.804	0.02137	750.14	878.34	2.762	0.93401	1.1505	397.35	1.3316	3.13E-05	0.049084	vapor
690	6	46.078	0.0217	759.65	889.86	2.7788	0.9385	1.154	400.29	1.2803	3.17E-05	0.049824	vapor
700	6	45.377	0.02204	769.19	901.42	2.7955	0.94292	1.1574	403.2	1.2313	3.20E-05	0.050561	vapor
710	6	44.698	0.02237	778.77	913.01	2.8119	0.94728	1.1608	406.09	1.1844	3.24E-05	0.051296	vapor
720	6	44.04	0.02271	788.39	924.63	2.8282	0.95157	1.1642	408.94	1.1394	3.27E-05	0.052028	vapor
730	6	43.403	0.02304	798.05	936.29	2.8442	0.9558	1.1676	411.77	1.0963	3.30E-05	0.052757	vapor
740	6	42.785	0.02337	807.75	947.98	2.8601	0.95995	1.171	414.57	1.055	3.34E-05	0.053485	vapor
750	6	42.185	0.02371	817.48	959.71	2.8759	0.96405	1.1744	417.34	1.0153	3.37E-05	0.054209	vapor
760	6	41.603	0.02404	827.25	971.47	2.8915	0.96808	1.1777	420.09	0.97714	3.40E-05	0.054931	vapor
770	6	41.037	0.02437	837.06	983.26	2.9069	0.97204	1.181	422.82	0.94049	3.44E-05	0.05565	vapor
780	6	40.488	0.0247	846.9	995.09	2.9221	0.97594	1.1842	425.52	0.90522	3.47E-05	0.056366	vapor
790	6	39.954	0.02503	856.78	1006.9	2.9372	0.97978	1.1875	428.21	0.87128	3.50E-05	0.057079	vapor
800	6	39.435	0.02536	866.69	1018.8	2.9522	0.98356	1.1906	430.87	0.83858	3.54E-05	0.05779	vapor
810	6	38.929	0.02569	876.64	1030.8	2.967	0.98727	1.1938	433.5	0.80707	3.57E-05	0.058498	vapor
820	6	38.437	0.02602	886.62	1042.7	2.9817	0.99093	1.1969	436.12	0.77669	3.60E-05	0.059203	vapor
830	6	37.958	0.02635	896.63	1054.7	2.9962	0.99452	1.2	438.72	0.74737	3.63E-05	0.059906	vapor
840	6	37.491	0.02667	906.68	1066.7	3.0106	0.99805	1.2031	441.3	0.71908	3.66E-05	0.060605	vapor
850	6	37.036	0.027	916.76	1078.8	3.0249	1.0015	1.2061	443.86	0.69174	3.70E-05	0.061302	vapor
860	6	36.593	0.02733	926.87	1090.8	3.039	1.0049	1.209	446.4	0.66533	3.73E-05	0.061996	vapor
870	6	36.16	0.02766	937.01	1102.9	3.053	1.0083	1.212	448.92	0.63979	3.76E-05	0.062687	vapor
880	6	35.738	0.02798	947.19	1115.1	3.0668	1.0116	1.2149	451.43	0.61509	3.79E-05	0.063375	vapor
890	6	35.326	0.02831	957.39	1127.2	3.0806	1.0149	1.2177	453.92	0.59118	3.82E-05	0.06406	vapor
900	6	34.924	0.02863	967.63	1139.4	3.0942	1.0181	1.2206	456.39	0.56803	3.85E-05	0.064743	vapor
910	6	34.531	0.02896	977.89	1151.7	3.1077	1.0212	1.2233	458.85	0.54561	3.88E-05	0.065422	vapor
920	6	34.147	0.02929	988.19	1163.9	3.1211	1.0243	1.2261	461.29	0.52388	3.91E-05	0.066099	vapor
930	6	33.772	0.02961	998.51	1176.2	3.1344	1.0273	1.2288	463.71	0.50282	3.94E-05	0.066773	vapor
940	6	33.406	0.02994	1008.9	1188.5	3.1475	1.0303	1.2314	466.12	0.48239	3.97E-05	0.067444	vapor
950	6	33.047	0.03026	1019.2	1200.8	3.1606	1.0332	1.2341	468.52	0.46256	4.00E-05	0.068112	vapor
960	6	32.697	0.03058	1029.6	1213.2	3.1735	1.0361	1.2366	470.9	0.44332	4.03E-05	0.068777	vapor
970	6	32.354	0.03091	1040.1	1225.5	3.1863	1.039	1.2392	473.26	0.42463	4.06E-05	0.06944	vapor
980	6	32.018	0.03123	1050.5	1237.9	3.199	1.0417	1.2417	475.62	0.40648	4.09E-05	0.070099	vapor
990	6	31.69	0.03156	1061	1250.4	3.2117	1.0445	1.2442	477.95	0.38884	4.12E-05	0.070756	vapor
1000	6	31.368	0.03188	1071.5	1262.8	3.2242	1.0472	1.2466	480.28	0.37169	4.15E-05	0.07141	vapor

1010	6	31.053	0.0322	1082.1	1275.3	3.2366	1.0498	1.249	482.59	0.35501	4.17E-05	0.072061	vapor
1020	6	30.745	0.03253	1092.6	1287.8	3.2489	1.0524	1.2514	484.89	0.33878	4.20E-05	0.072709	vapor
1030	6	30.442	0.03285	1103.2	1300.3	3.2611	1.055	1.2537	487.18	0.32299	4.23E-05	0.073355	vapor
1040	6	30.146	0.03317	1113.8	1312.9	3.2733	1.0575	1.256	489.46	0.30762	4.26E-05	0.073998	vapor
1050	6	29.856	0.03349	1124.5	1325.4	3.2853	1.06	1.2583	491.72	0.29265	4.29E-05	0.074637	vapor
1060	6	29.571	0.03382	1135.1	1338	3.2972	1.0624	1.2605	493.97	0.27807	4.32E-05	0.075275	vapor
1070	6	29.292	0.03414	1145.8	1350.7	3.3091	1.0648	1.2627	496.21	0.26386	4.34E-05	0.075909	vapor
1080	6	29.018	0.03446	1156.5	1363.3	3.3208	1.0672	1.2648	498.44	0.25002	4.37E-05	0.076541	vapor

Table 29. Isobaric CO_2 Properties at 12 MPa. Source: [18].

Temperature (K)	Pressure (MPa)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Cv (J/g*K)	Cp (J/g*K)	Sound Spd. (m/s)	Joule-Thomson (K/MPa)	Viscosity (Pa*s)	Therm. Cond. (W/m*K)	Phase
220	12	1189.4	0.00084	79.995	90.084	0.5229	0.98262	1.8939	1013.5	-0.17165	0.000264	0.18513	liquid
230	12	1155.6	0.00087	98.701	109.08	0.6074	0.96809	1.9078	948.76	-0.14159	0.000225	0.17288	liquid
240	12	1120.2	0.00089	117.56	128.27	0.689	0.95523	1.9314	884.26	-0.10245	0.000193	0.16103	liquid
250	12	1082.8	0.00092	136.67	147.75	0.7686	0.94413	1.967	819.4	-0.051267	1.66E-04	0.1495	liquid
260	12	1042.8	0.00096	156.16	167.66	0.8467	0.93504	2.0182	753.5	0.016505	1.43E-04	0.13823	liquid
270	12	999.47	0.001	176.18	188.19	0.9241	0.92838	2.091	685.85	0.10814	1.23E-04	0.12714	liquid
280	12	951.55	0.00105	196.98	209.59	1.0019	0.92461	2.1961	615.65	0.23623	1.06E-04	0.11613	liquid
290	12	897.11	0.00111	218.91	232.29	1.0816	0.92515	2.3558	541.69	0.42466	9.08E-05	0.10506	liquid
300	12	832.47	0.0012	242.67	257.08	1.1656	0.93421	2.6306	462.54	0.7252	7.67E-05	0.093737	liquid
310	12	749.85	0.00133	269.71	285.71	1.2594	0.95242	3.1566	378.82	1.2558	6.30E-05	0.081883	supercritical
320	12	632.21	0.00158	303.28	322.26	1.3753	0.98009	4.2711	296.05	2.3095	4.85E-05	0.069697	supercritical
330	12	476.55	0.0021	344.85	370.03	1.5223	1.0027	4.8317	245.01	3.9395	3.49E-05	0.057436	supercritical
340	12	367.79	0.00272	378.48	411.11	1.645	0.95248	3.3822	241.54	4.8966	2.82E-05	0.046212	supercritical
350	12	309.7	0.00323	401.28	440.02	1.7289	0.90839	2.5062	248.93	5.1406	2.56E-05	0.04013	supercritical
360	12	273.74	0.00365	418.8	462.64	1.7927	0.88238	2.062	257.21	5.0899	2.44E-05	0.03701	supercritical
370	12	248.59	0.00402	433.6	481.88	1.8454	0.86603	1.8062	265.2	4.926	2.38E-05	0.035347	supercritical
380	12	229.58	0.00436	446.8	499.07	1.8912	0.85536	1.6428	272.72	4.7188	2.35E-05	0.034471	supercritical
390	12	214.47	0.00466	458.95	514.9	1.9324	0.84847	1.5309	279.79	4.4978	2.34E-05	0.034061	supercritical
400	12	202.03	0.00495	470.39	529.79	1.9701	0.84424	1.4503	286.44	4.2765	2.35E-05	0.033945	supercritical
410	12	191.52	0.00522	481.32	543.98	2.0051	0.84196	1.3903	292.72	4.0614	2.36E-05	0.034026	supercritical
420	12	182.46	0.00548	491.87	557.64	2.038	0.84116	1.3443	298.68	3.8556	2.37E-05	0.034244	supercritical
430	12	174.52	0.00573	502.14	570.9	2.0692	0.84149	1.3085	304.37	3.6604	2.39E-05	0.034558	supercritical
440	12	167.49	0.00597	512.19	583.84	2.099	0.84272	1.2802	309.81	3.4762	2.42E-05	0.034937	supercritical
450	12	161.19	0.0062	522.07	596.52	2.1275	0.84465	1.2575	315.03	3.3029	2.44E-05	0.035293	supercritical
460	12	155.49	0.00643	531.83	609	2.1549	0.84715	1.2393	320.05	3.1401	2.47E-05	0.035854	supercritical
470	12	150.31	0.00665	541.48	621.32	2.1814	0.85009	1.2246	324.9	2.9872	2.50E-05	0.036441	supercritical
480	12	145.56	0.00687	551.06	633.5	2.2071	0.85339	1.2127	329.59	2.8437	2.53E-05	0.037048	supercritical
490	12	141.18	0.00708	560.58	645.58	2.232	0.85699	1.203	334.13	2.7089	2.56E-05	0.037673	supercritical
500	12	137.13	0.00729	570.06	657.57	2.2562	0.86081	1.1952	338.54	2.5822	2.59E-05	0.038312	supercritical
510	12	133.36	0.0075	579.51	669.49	2.2798	0.86482	1.189	342.83	2.4631	2.62E-05	0.038963	supercritical
520	12	129.85	0.0077	588.94	681.35	2.3028	0.86898	1.184	347.01	2.351	2.66E-05	0.039624	supercritical
530	12	126.56	0.0079	598.35	693.17	2.3253	0.87324	1.1801	351.09	2.2454	2.69E-05	0.040294	supercritical
540	12	123.46	0.0081	607.76	704.96	2.3474	0.8776	1.1772	355.07	2.1458	2.72E-05	0.04097	supercritical
550	12	120.55	0.0083	617.17	716.72	2.369	0.88202	1.175	358.96	2.0518	2.76E-05	0.041653	supercritical
560	12	117.8	0.00849	626.59	728.46	2.3901	0.88649	1.1735	362.77	1.963	2.79E-05	0.04234	supercritical
570	12	115.2	0.00868	636.02	740.19	2.4109	0.89099	1.1725	366.51	1.879	2.83E-05	0.043032	supercritical
580	12	112.73	0.00887	645.46	751.91	2.4313	0.89551	1.172	370.17	1.7994	2.86E-05	0.043726	supercritical
590	12	110.38	0.00906	654.92	763.63	2.4513	0.90003	1.172	373.76	1.724	2.89E-05	0.044424	supercritical
600	12	108.15	0.00925	664.39	775.35	2.471	0.90454	1.1723	377.29	1.6525	2.93E-05	0.045124	supercritical

610	12	106.02	0.00943	673.89	787.08	2.4904	0.90905	1.173	380.76	1.5846	2.96E-05	0.045825	supercritical
620	12	103.99	0.00962	683.41	798.81	2.5095	0.91353	1.1739	384.18	1.52	3.00E-05	0.046528	supercritical
630	12	102.04	0.0098	692.96	810.56	2.5282	0.91799	1.1751	387.54	1.4586	3.03E-05	0.047231	supercritical
640	12	100.18	0.00998	702.53	822.31	2.5468	0.92242	1.1764	390.85	1.4	3.06E-05	0.047936	supercritical
650	12	98.391	0.01016	712.12	834.09	2.565	0.92682	1.178	394.11	1.3443	3.10E-05	0.04864	supercritical
660	12	96.676	0.01034	721.75	845.87	2.583	0.93118	1.1797	397.32	1.2911	3.13E-05	0.049345	supercritical
670	12	95.029	0.01052	731.4	857.68	2.6008	0.93549	1.1815	400.49	1.2403	3.16E-05	0.050049	supercritical
680	12	93.443	0.0107	741.08	869.5	2.6183	0.93977	1.1835	403.62	1.1917	3.20E-05	0.050753	supercritical
690	12	91.917	0.01088	750.8	881.35	2.6356	0.94399	1.1855	406.7	1.1453	3.23E-05	0.051456	supercritical
700	12	90.446	0.01106	760.54	893.21	2.6526	0.94817	1.1876	409.75	1.1008	3.26E-05	0.052159	supercritical
710	12	89.026	0.01123	770.31	905.1	2.6695	0.9523	1.1898	412.77	1.0582	3.30E-05	0.05286	supercritical
720	12	87.656	0.01141	780.11	917.01	2.6862	0.95637	1.1921	415.75	1.0174	3.33E-05	0.05356	supercritical
730	12	86.332	0.01158	789.95	928.94	2.7026	0.9604	1.1944	418.69	0.97828	3.36E-05	0.05426	supercritical
740	12	85.051	0.01176	799.81	940.9	2.7189	0.96437	1.1968	421.6	0.9407	3.39E-05	0.054957	supercritical
750	12	83.812	0.01193	809.7	952.88	2.735	0.96829	1.1992	424.48	0.9046	3.43E-05	0.055654	supercritical
760	12	82.612	0.01211	819.63	964.88	2.7509	0.97215	1.2016	427.33	0.86991	3.46E-05	0.056348	supercritical
770	12	81.45	0.01228	829.58	976.91	2.7666	0.97596	1.204	430.15	0.83653	3.49E-05	0.057041	supercritical
780	12	80.322	0.01245	839.57	988.96	2.7821	0.97972	1.2065	432.95	0.80441	3.52E-05	0.057733	supercritical
790	12	79.229	0.01262	849.58	1001	2.7975	0.98342	1.2089	435.71	0.77348	3.55E-05	0.058422	supercritical
800	12	78.168	0.01279	859.63	1013.1	2.8128	0.98707	1.2114	438.45	0.74368	3.58E-05	0.05911	supercritical
810	12	77.137	0.01296	869.7	1025.3	2.8278	0.99066	1.2139	441.17	0.71494	3.62E-05	0.059795	supercritical
820	12	76.135	0.01314	879.81	1037.4	2.8427	0.9942	1.2164	443.86	0.68722	3.65E-05	0.060479	supercritical
830	12	75.161	0.01331	889.94	1049.6	2.8575	0.99768	1.2188	446.53	0.66046	3.68E-05	0.06116	supercritical
840	12	74.214	0.01348	900.1	1061.8	2.8721	1.0011	1.2213	449.17	0.63462	3.71E-05	0.06184	supercritical
850	12	73.292	0.01364	910.29	1074	2.8866	1.0045	1.2237	451.8	0.60965	3.74E-05	0.062517	supercritical
860	12	72.395	0.01381	920.51	1086.3	2.9009	1.0078	1.2262	454.4	0.58552	3.77E-05	0.063192	supercritical
870	12	71.521	0.01398	930.76	1098.5	2.9151	1.0111	1.2286	456.98	0.56217	3.80E-05	0.063864	supercritical
880	12	70.669	0.01415	941.04	1110.8	2.9291	1.0143	1.231	459.54	0.53958	3.83E-05	0.064535	supercritical
890	12	69.839	0.01432	951.34	1123.2	2.9431	1.0175	1.2334	462.08	0.51771	3.86E-05	0.065203	supercritical
900	12	69.029	0.01449	961.67	1135.5	2.9569	1.0206	1.2358	464.6	0.49653	3.89E-05	0.065869	supercritical
910	12	68.24	0.01465	972.03	1147.9	2.9705	1.0237	1.2382	467.1	0.47601	3.92E-05	0.066532	supercritical
920	12	67.469	0.01482	982.42	1160.3	2.9841	1.0267	1.2405	469.59	0.45611	3.95E-05	0.067193	supercritical
930	12	66.717	0.01499	992.83	1172.7	2.9975	1.0296	1.2428	472.06	0.43682	3.98E-05	0.067852	supercritical
940	12	65.982	0.01516	1003.3	1185.1	3.0108	1.0326	1.2451	474.51	0.41809	4.01E-05	0.068508	supercritical
950	12	65.264	0.01532	1013.7	1197.6	3.024	1.0354	1.2474	476.94	0.39992	4.04E-05	0.069161	supercritical
960	12	64.563	0.01549	1024.2	1210.1	3.0371	1.0383	1.2496	479.36	0.38228	4.06E-05	0.069813	supercritical
970	12	63.878	0.01566	1034.7	1222.6	3.05	1.0411	1.2518	481.76	0.36514	4.09E-05	0.070461	supercritical
980	12	63.207	0.01582	1045.3	1235.1	3.0629	1.0438	1.254	484.14	0.34848	4.12E-05	0.071108	supercritical
990	12	62.552	0.01599	1055.8	1247.7	3.0756	1.0465	1.2562	486.51	0.33229	4.15E-05	0.071751	supercritical
1000	12	61.911	0.01615	1066.4	1260.2	3.0882	1.0491	1.2583	488.87	0.31655	4.18E-05	0.072393	supercritical
1010	12	61.283	0.01632	1077	1272.8	3.1008	1.0517	1.2605	491.21	0.30123	4.21E-05	0.073031	supercritical
1020	12	60.669	0.01648	1087.7	1285.4	3.1132	1.0543	1.2625	493.53	0.28632	4.23E-05	0.073668	supercritical

1030	12	60.067	0.01665	1098.3	1298.1	3.1255	1.0568	1.2646	495.85	0.27181	4.26E-05	0.074302	supercritical
1040	12	59.478	0.01681	1109	1310.7	3.1378	1.0593	1.2667	498.15	0.25768	4.29E-05	0.074933	supercritical
1050	12	58.901	0.01698	1119.7	1323.4	3.1499	1.0617	1.2687	500.43	0.24392	4.32E-05	0.075562	supercritical
1060	12	58.336	0.01714	1130.4	1336.1	3.1619	1.0641	1.2707	502.7	0.23051	4.35E-05	0.076188	supercritical
1070	12	57.781	0.01731	1141.2	1348.8	3.1739	1.0665	1.2726	504.96	0.21743	4.37E-05	0.076812	supercritical
1080	12	57.238	0.01747	1151.9	1361.6	3.1857	1.0688	1.2746	507.21	0.20469	4.40E-05	0.077433	supercritical
1090	12	56.706	0.01764	1162.7	1374.3	3.1975	1.0711	1.2765	509.45	0.19226	4.43E-05	0.078052	supercritical
1100	12	56.183	0.0178	1173.5	1387.1	3.2091	1.0733	1.2784	511.67	0.18013	4.45E-05	0.078669	supercritical

Table 30. Saturated Liquid CO_2 Properties. Source: [18].

Temperature (K)	Pressure (MPa)	Density (l, kg/m3)	Volume (l, m3/kg)	Internal Energy (l, kJ/kg)	Enthalpy (l, kJ/kg)	Entropy (l, J/g*K)	Cv (l, J/g*K)	Cp (l, J/g*K)	Sound Spd. (l, m/s)	Joule-Thomson (l, K/MPa)	Viscosity (l, Pa*s)	Therm. Cond. (l, W/m*K)
216.59	0.51796	1178.5	8.486E-04	79.596	80.036	0.52132	0.97466	1.9532	975.85	-0.1443	0.0002567	0.18063
216.74	0.52126	1177.9	8.489E-04	79.879	80.321	0.52263	0.97445	1.9535	974.79	-0.1438	0.00025605	0.18043
216.88	0.52457	1177.4	8.493E-04	80.162	80.607	0.52393	0.97424	1.9539	973.73	-0.1433	0.0002554	0.18024
217.03	0.52789	1176.9	8.497E-04	80.445	80.893	0.52524	0.97403	1.9542	972.68	-0.1428	0.00025476	0.18005
217.18	0.53124	1176.4	8.501E-04	80.728	81.179	0.52654	0.97382	1.9546	971.62	-0.1423	0.00025411	0.17986
217.32	0.53459	1175.8	8.505E-04	81.011	81.466	0.52785	0.97361	1.9549	970.57	-0.1417	0.00025347	0.17967
217.47	0.53797	1175.3	8.508E-04	81.294	81.752	0.52915	0.9734	1.9553	969.51	-0.1412	0.00025283	0.17947
217.61	0.54136	1174.8	8.512E-04	81.577	82.038	0.53045	0.9732	1.9556	968.46	-0.1407	0.00025219	0.17928
217.76	0.54476	1174.3	8.516E-04	81.86	82.324	0.53175	0.97299	1.956	967.4	-0.1402	0.00025155	0.17909
217.91	0.54818	1173.7	8.520E-04	82.144	82.611	0.53305	0.97278	1.9563	966.35	-0.1396	0.00025092	0.1789
218.05	0.55162	1173.2	8.524E-04	82.427	82.897	0.53435	0.97257	1.9567	965.29	-0.1391	0.00025029	0.17871
218.2	0.55508	1172.7	8.527E-04	82.71	83.183	0.53565	0.97236	1.9571	964.24	-0.1386	0.00024965	0.17851
218.34	0.55855	1172.2	8.531E-04	82.993	83.47	0.53695	0.97216	1.9574	963.18	-0.138	0.00024903	0.17832
218.49	0.56203	1171.6	8.535E-04	83.277	83.756	0.53825	0.97195	1.9578	962.13	-0.1375	0.0002484	0.17813
218.63	0.56554	1171.1	8.539E-04	83.56	84.043	0.53955	0.97174	1.9582	961.07	-0.137	0.00024777	0.17794
218.78	0.56906	1170.6	8.543E-04	83.844	84.33	0.54085	0.97154	1.9585	960.02	-0.1364	0.00024715	0.17775
218.93	0.57259	1170	8.547E-04	84.127	84.616	0.54214	0.97133	1.9589	958.97	-0.1359	0.00024653	0.17756
219.07	0.57615	1169.5	8.551E-04	84.411	84.903	0.54344	0.97113	1.9593	957.91	-0.1353	0.00024591	0.17737
219.22	0.57972	1169	8.554E-04	84.694	85.19	0.54473	0.97092	1.9597	956.86	-0.1348	0.00024529	0.17717
219.36	0.5833	1168.5	8.558E-04	84.978	85.477	0.54603	0.97072	1.9601	955.81	-0.1342	0.00024467	0.17698
219.51	0.5869	1167.9	8.562E-04	85.261	85.764	0.54732	0.97051	1.9605	954.75	-0.1337	0.00024406	0.17679
219.66	0.59052	1167.4	8.566E-04	85.545	86.051	0.54861	0.97031	1.9608	953.7	-0.1331	0.00024345	0.1766
219.8	0.59416	1166.9	8.570E-04	85.829	86.338	0.54991	0.9701	1.9612	952.65	-0.1326	0.00024283	0.17641
219.95	0.59781	1166.3	8.574E-04	86.112	86.625	0.5512	0.9699	1.9616	951.59	-0.132	0.00024223	0.17622
220.09	0.60148	1165.8	8.578E-04	86.396	86.912	0.55249	0.9697	1.962	950.54	-0.1314	0.00024162	0.17603
220.24	0.60517	1165.3	8.582E-04	86.68	87.199	0.55378	0.96949	1.9624	949.49	-0.1309	0.00024101	0.17584
220.39	0.60887	1164.7	8.586E-04	86.964	87.487	0.55507	0.96929	1.9629	948.43	-0.1303	0.00024041	0.17565
220.53	0.61259	1164.2	8.590E-04	87.248	87.774	0.55636	0.96909	1.9633	947.38	-0.1297	0.00023981	0.17546
220.68	0.61633	1163.7	8.594E-04	87.532	88.061	0.55765	0.96889	1.9637	946.33	-0.1292	0.00023921	0.17527
220.82	0.62009	1163.1	8.598E-04	87.816	88.349	0.55893	0.96868	1.9641	945.28	-0.1286	0.00023861	0.17508
220.97	0.62386	1162.6	8.601E-04	88.1	88.636	0.56022	0.96848	1.9645	944.22	-0.128	0.00023801	0.17489
221.11	0.62765	1162.1	8.605E-04	88.384	88.924	0.56151	0.96828	1.9649	943.17	-0.1274	0.00023742	0.1747
221.26	0.63146	1161.5	8.609E-04	88.668	89.212	0.56279	0.96808	1.9654	942.12	-0.1269	0.00023682	0.17451
221.41	0.63528	1161	8.613E-04	88.952	89.499	0.56408	0.96788	1.9658	941.07	-0.1263	0.00023623	0.17432
221.55	0.63912	1160.5	8.617E-04	89.236	89.787	0.56536	0.96768	1.9662	940.01	-0.1257	0.00023564	0.17413
221.7	0.64298	1159.9	8.621E-04	89.521	90.075	0.56665	0.96748	1.9667	938.96	-0.1251	0.00023505	0.17394
221.84	0.64686	1159.4	8.625E-04	89.805	90.363	0.56793	0.96728	1.9671	937.91	-0.1245	0.00023447	0.17375
221.99	0.65075	1158.8	8.629E-04	90.089	90.651	0.56921	0.96708	1.9675	936.86	-0.1239	0.00023388	0.17356

222.14	0.65466	1158.3	8.633E-04	90.374	90.939	0.57049	0.96688	1.968	935.81	-0.1233	0.0002333	0.17337
222.28	0.65859	1157.8	8.637E-04	90.658	91.227	0.57177	0.96668	1.9684	934.75	-0.1227	0.00023272	0.17318
222.43	0.66254	1157.2	8.641E-04	90.943	91.515	0.57305	0.96648	1.9689	933.7	-0.1221	0.00023214	0.17299
222.57	0.6665	1156.7	8.645E-04	91.227	91.803	0.57433	0.96629	1.9693	932.65	-0.1215	0.00023156	0.1728
222.72	0.67049	1156.2	8.649E-04	91.512	92.092	0.57561	0.96609	1.9698	931.6	-0.1209	0.00023099	0.17261
222.87	0.67449	1155.6	8.653E-04	91.796	92.38	0.57689	0.96589	1.9703	930.55	-0.1203	0.00023041	0.17242
223.01	0.67851	1155.1	8.657E-04	92.081	92.668	0.57817	0.96569	1.9707	929.5	-0.1197	0.00022984	0.17224
223.16	0.68254	1154.5	8.662E-04	92.366	92.957	0.57945	0.9655	1.9712	928.44	-0.1191	0.00022927	0.17205
223.3	0.6866	1154	8.666E-04	92.651	93.246	0.58073	0.9653	1.9717	927.39	-0.1184	0.0002287	0.17186
223.45	0.69067	1153.5	8.670E-04	92.935	93.534	0.582	0.96511	1.9721	926.34	-0.1178	0.00022813	0.17167
223.59	0.69476	1152.9	8.674E-04	93.22	93.823	0.58328	0.96491	1.9726	925.29	-0.1172	0.00022757	0.17148
223.74	0.69887	1152.4	8.678E-04	93.505	94.112	0.58455	0.96471	1.9731	924.24	-0.1166	0.000227	0.17129
223.89	0.70299	1151.8	8.682E-04	93.79	94.4	0.58583	0.96452	1.9736	923.19	-0.1159	0.00022644	0.1711
224.03	0.70714	1151.3	8.686E-04	94.075	94.689	0.5871	0.96433	1.9741	922.13	-0.1153	0.00022588	0.17092
224.18	0.7113	1150.7	8.690E-04	94.36	94.978	0.58837	0.96413	1.9745	921.08	-0.1147	0.00022532	0.17073
224.32	0.71548	1150.2	8.694E-04	94.645	95.267	0.58965	0.96394	1.975	920.03	-0.114	0.00022476	0.17054
224.47	0.71968	1149.7	8.698E-04	94.931	95.557	0.59092	0.96374	1.9755	918.98	-0.1134	0.0002242	0.17035
224.62	0.7239	1149.1	8.702E-04	95.216	95.846	0.59219	0.96355	1.976	917.93	-0.1128	0.00022365	0.17016
224.76	0.72814	1148.6	8.707E-04	95.501	96.135	0.59346	0.96336	1.9765	916.88	-0.1121	0.00022309	0.16998
224.91	0.73239	1148	8.711E-04	95.786	96.424	0.59473	0.96316	1.977	915.82	-0.1115	0.00022254	0.16979
225.05	0.73666	1147.5	8.715E-04	96.072	96.714	0.596	0.96297	1.9776	914.77	-0.1108	0.00022199	0.1696
225.2	0.74096	1146.9	8.719E-04	96.357	97.003	0.59727	0.96278	1.9781	913.72	-0.1102	0.00022144	0.16941
225.35	0.74527	1146.4	8.723E-04	96.643	97.293	0.59854	0.96259	1.9786	912.67	-0.1095	0.0002209	0.16922
225.49	0.7496	1145.8	8.727E-04	96.928	97.582	0.59981	0.9624	1.9791	911.62	-0.1088	0.00022035	0.16904
225.64	0.75395	1145.3	8.732E-04	97.214	97.872	0.60108	0.96221	1.9796	910.57	-0.1082	0.00021981	0.16885
225.78	0.75831	1144.7	8.736E-04	97.5	98.162	0.60234	0.96202	1.9802	909.51	-0.1075	0.00021926	0.16866
225.93	0.7627	1144.2	8.740E-04	97.785	98.452	0.60361	0.96183	1.9807	908.46	-0.1068	0.00021872	0.16848
226.08	0.76711	1143.6	8.744E-04	98.071	98.742	0.60488	0.96164	1.9812	907.41	-0.1062	0.00021818	0.16829
226.22	0.77153	1143.1	8.748E-04	98.357	99.032	0.60614	0.96145	1.9818	906.36	-0.1055	0.00021765	0.1681
226.37	0.77597	1142.5	8.753E-04	98.643	99.322	0.60741	0.96126	1.9823	905.31	-0.1048	0.00021711	0.16791
226.51	0.78044	1142	8.757E-04	98.929	99.612	0.60867	0.96107	1.9828	904.26	-0.1041	0.00021657	0.16773
226.66	0.78492	1141.4	8.761E-04	99.215	99.902	0.60993	0.96088	1.9834	903.2	-0.1035	0.00021604	0.16754
226.8	0.78942	1140.9	8.765E-04	99.501	100.19	0.6112	0.96069	1.9839	902.15	-0.1028	0.00021551	0.16735
226.95	0.79394	1140.3	8.769E-04	99.787	100.48	0.61246	0.96051	1.9845	901.1	-0.1021	0.00021498	0.16717
227.1	0.79848	1139.8	8.774E-04	100.07	100.77	0.61372	0.96032	1.9851	900.05	-0.1014	0.00021445	0.16698
227.24	0.80304	1139.2	8.778E-04	100.36	101.06	0.61498	0.96013	1.9856	899	-0.1007	0.00021392	0.16679
227.39	0.80761	1138.7	8.782E-04	100.65	101.35	0.61624	0.95995	1.9862	897.94	-0.1	0.0002134	0.16661
227.53	0.81221	1138.1	8.786E-04	100.93	101.65	0.6175	0.95976	1.9868	896.89	-0.0993	0.00021287	0.16642
227.68	0.81683	1137.6	8.791E-04	101.22	101.94	0.61876	0.95957	1.9873	895.84	-0.0986	0.00021235	0.16623
227.83	0.82146	1137	8.795E-04	101.5	102.23	0.62002	0.95939	1.9879	894.79	-0.0979	0.00021183	0.16605
227.97	0.82612	1136.5	8.799E-04	101.79	102.52	0.62128	0.9592	1.9885	893.73	-0.0972	0.00021131	0.16586

228.12	0.8308	1135.9	8.804E-04	102.08	102.81	0.62254	0.95902	1.9891	892.68	-0.0965	0.00021079	0.16568
228.26	0.83549	1135.3	8.808E-04	102.36	103.1	0.6238	0.95883	1.9897	891.63	-0.0958	0.00021027	0.16549
228.41	0.84021	1134.8	8.812E-04	102.65	103.39	0.62505	0.95865	1.9903	890.58	-0.095	0.00020976	0.1653
228.56	0.84494	1134.2	8.817E-04	102.94	103.68	0.62631	0.95847	1.9909	889.52	-0.0943	0.00020924	0.16512
228.7	0.8497	1133.7	8.821E-04	103.22	103.97	0.62757	0.95828	1.9915	888.47	-0.0936	0.00020873	0.16493
228.85	0.85447	1133.1	8.825E-04	103.51	104.27	0.62882	0.9581	1.9921	887.42	-0.0929	0.00020822	0.16475
228.99	0.85927	1132.6	8.830E-04	103.8	104.56	0.63008	0.95792	1.9927	886.36	-0.0921	0.00020771	0.16456
229.14	0.86408	1132	8.834E-04	104.09	104.85	0.63133	0.95774	1.9933	885.31	-0.0914	0.0002072	0.16437
229.28	0.86892	1131.4	8.838E-04	104.37	105.14	0.63259	0.95756	1.9939	884.26	-0.0907	0.00020669	0.16419
229.43	0.87377	1130.9	8.843E-04	104.66	105.43	0.63384	0.95737	1.9945	883.2	-0.0899	0.00020619	0.164
229.58	0.87865	1130.3	8.847E-04	104.95	105.72	0.63509	0.95719	1.9951	882.15	-0.0892	0.00020568	0.16382
229.72	0.88354	1129.8	8.852E-04	105.23	106.02	0.63635	0.95701	1.9958	881.1	-0.0884	0.00020518	0.16363
229.87	0.88846	1129.2	8.856E-04	105.52	106.31	0.6376	0.95683	1.9964	880.04	-0.0877	0.00020468	0.16345
230.01	0.89339	1128.6	8.860E-04	105.81	106.6	0.63885	0.95665	1.997	878.99	-0.0869	0.00020418	0.16326
230.16	0.89835	1128.1	8.865E-04	106.1	106.89	0.6401	0.95647	1.9977	877.93	-0.0862	0.00020368	0.16308
230.31	0.90333	1127.5	8.869E-04	106.38	107.19	0.64135	0.9563	1.9983	876.88	-0.0854	0.00020318	0.16289
230.45	0.90832	1126.9	8.874E-04	106.67	107.48	0.6426	0.95612	1.999	875.83	-0.0846	0.00020269	0.16271
230.6	0.91334	1126.4	8.878E-04	106.96	107.77	0.64385	0.95594	1.9996	874.77	-0.0839	0.00020219	0.16252
230.74	0.91838	1125.8	8.883E-04	107.25	108.06	0.6451	0.95576	2.0003	873.72	-0.0831	0.0002017	0.16234
230.89	0.92344	1125.2	8.887E-04	107.53	108.36	0.64635	0.95558	2.0009	872.66	-0.0823	0.00020121	0.16215
231.04	0.92852	1124.7	8.891E-04	107.82	108.65	0.6476	0.95541	2.0016	871.61	-0.0816	0.00020072	0.16197
231.18	0.93362	1124.1	8.896E-04	108.11	108.94	0.64885	0.95523	2.0023	870.55	-0.0808	0.00020023	0.16178
231.33	0.93874	1123.5	8.900E-04	108.4	109.23	0.65009	0.95505	2.0029	869.5	-0.08	0.00019974	0.1616
231.47	0.94388	1123	8.905E-04	108.69	109.53	0.65134	0.95488	2.0036	868.44	-0.0792	0.00019925	0.16141
231.62	0.94904	1122.4	8.909E-04	108.97	109.82	0.65259	0.9547	2.0043	867.39	-0.0784	0.00019877	0.16123
231.76	0.95423	1121.8	8.914E-04	109.26	110.11	0.65383	0.95453	2.005	866.33	-0.0776	0.00019828	0.16105
231.91	0.95943	1121.3	8.918E-04	109.55	110.41	0.65508	0.95435	2.0056	865.28	-0.0768	0.0001978	0.16086
232.06	0.96466	1120.7	8.923E-04	109.84	110.7	0.65632	0.95418	2.0063	864.22	-0.076	0.00019732	0.16068
232.2	0.96991	1120.1	8.928E-04	110.13	110.99	0.65757	0.95401	2.007	863.16	-0.0752	0.00019684	0.16049
232.35	0.97517	1119.6	8.932E-04	110.42	111.29	0.65881	0.95383	2.0077	862.11	-0.0744	0.00019636	0.16031
232.49	0.98046	1119	8.937E-04	110.71	111.58	0.66005	0.95366	2.0084	861.05	-0.0736	0.00019588	0.16013
232.64	0.98577	1118.4	8.941E-04	110.99	111.88	0.6613	0.95349	2.0091	859.99	-0.0728	0.00019541	0.15994
232.79	0.99111	1117.9	8.946E-04	111.28	112.17	0.66254	0.95331	2.0099	858.94	-0.0719	0.00019493	0.15976
232.93	0.99646	1117.3	8.950E-04	111.57	112.46	0.66378	0.95314	2.0106	857.88	-0.0711	0.00019446	0.15957
233.08	1.0018	1116.7	8.955E-04	111.86	112.76	0.66502	0.95297	2.0113	856.82	-0.0703	0.00019399	0.15939
233.22	1.0072	1116.1	8.960E-04	112.15	113.05	0.66626	0.9528	2.012	855.77	-0.0695	0.00019352	0.15921
233.37	1.0126	1115.6	8.964E-04	112.44	113.35	0.66751	0.95263	2.0128	854.71	-0.0686	0.00019305	0.15902
233.52	1.0181	1115	8.969E-04	112.73	113.64	0.66875	0.95246	2.0135	853.65	-0.0678	0.00019258	0.15884
233.66	1.0235	1114.4	8.973E-04	113.02	113.94	0.66999	0.95229	2.0142	852.59	-0.067	0.00019211	0.15866
233.81	1.029	1113.8	8.978E-04	113.31	114.23	0.67123	0.95212	2.015	851.54	-0.0661	0.00019164	0.15847
233.95	1.0345	1113.3	8.983E-04	113.6	114.52	0.67246	0.95195	2.0157	850.48	-0.0653	0.00019118	0.15829

234.1	1.0401	1112.7	8.987E-04	113.88	114.82	0.6737	0.95179	2.0165	849.42	-0.0644	0.00019072	0.15811
234.25	1.0456	1112.1	8.992E-04	114.17	115.11	0.67494	0.95162	2.0172	848.36	-0.0635	0.00019025	0.15792
234.39	1.0512	1111.5	8.997E-04	114.46	115.41	0.67618	0.95145	2.018	847.3	-0.0627	0.00018979	0.15774
234.54	1.0568	1110.9	9.001E-04	114.75	115.7	0.67742	0.95128	2.0188	846.24	-0.0618	0.00018933	0.15756
234.68	1.0624	1110.4	9.006E-04	115.04	116	0.67865	0.95112	2.0195	845.18	-0.061	0.00018887	0.15737
234.83	1.068	1109.8	9.011E-04	115.33	116.3	0.67989	0.95095	2.0203	844.12	-0.0601	0.00018842	0.15719
234.97	1.0737	1109.2	9.015E-04	115.62	116.59	0.68113	0.95078	2.0211	843.06	-0.0592	0.00018796	0.15701
235.12	1.0794	1108.6	9.020E-04	115.91	116.89	0.68236	0.95062	2.0219	842	-0.0583	0.00018751	0.15682
235.27	1.0851	1108	9.025E-04	116.2	117.18	0.6836	0.95045	2.0227	840.94	-0.0574	0.00018705	0.15664
235.41	1.0908	1107.5	9.030E-04	116.49	117.48	0.68483	0.95029	2.0235	839.88	-0.0566	0.0001866	0.15646
235.56	1.0965	1106.9	9.034E-04	116.78	117.77	0.68607	0.95013	2.0243	838.82	-0.0557	0.00018615	0.15628
235.7	1.1023	1106.3	9.039E-04	117.07	118.07	0.6873	0.94996	2.0251	837.76	-0.0548	0.0001857	0.15609
235.85	1.1081	1105.7	9.044E-04	117.36	118.37	0.68854	0.9498	2.0259	836.7	-0.0539	0.00018525	0.15591
236	1.1139	1105.1	9.049E-04	117.65	118.66	0.68977	0.94964	2.0267	835.64	-0.053	0.0001848	0.15573
236.14	1.1198	1104.6	9.054E-04	117.94	118.96	0.691	0.94947	2.0275	834.57	-0.0521	0.00018436	0.15555
236.29	1.1256	1104	9.058E-04	118.24	119.25	0.69223	0.94931	2.0283	833.51	-0.0511	0.00018391	0.15536
236.43	1.1315	1103.4	9.063E-04	118.53	119.55	0.69347	0.94915	2.0291	832.45	-0.0502	0.00018347	0.15518
236.58	1.1374	1102.8	9.068E-04	118.82	119.85	0.6947	0.94899	2.03	831.39	-0.0493	0.00018302	0.155
236.73	1.1433	1102.2	9.073E-04	119.11	120.15	0.69593	0.94883	2.0308	830.32	-0.0484	0.00018258	0.15482
236.87	1.1493	1101.6	9.078E-04	119.4	120.44	0.69716	0.94867	2.0317	829.26	-0.0474	0.00018214	0.15464
237.02	1.1552	1101	9.082E-04	119.69	120.74	0.69839	0.94851	2.0325	828.2	-0.0465	0.0001817	0.15445
237.16	1.1612	1100.4	9.087E-04	119.98	121.04	0.69962	0.94835	2.0334	827.13	-0.0456	0.00018126	0.15427
237.31	1.1673	1099.9	9.092E-04	120.27	121.33	0.70085	0.94819	2.0342	826.07	-0.0446	0.00018083	0.15409
237.45	1.1733	1099.3	9.097E-04	120.56	121.63	0.70208	0.94804	2.0351	825	-0.0437	0.00018039	0.15391
237.6	1.1794	1098.7	9.102E-04	120.85	121.93	0.70331	0.94788	2.0359	823.94	-0.0427	0.00017995	0.15373
237.75	1.1855	1098.1	9.107E-04	121.15	122.23	0.70454	0.94772	2.0368	822.87	-0.0418	0.00017952	0.15355
237.89	1.1916	1097.5	9.112E-04	121.44	122.52	0.70577	0.94756	2.0377	821.81	-0.0408	0.00017909	0.15336
238.04	1.1977	1096.9	9.117E-04	121.73	122.82	0.707	0.94741	2.0386	820.74	-0.0399	0.00017866	0.15318
238.18	1.2039	1096.3	9.122E-04	122.02	123.12	0.70823	0.94725	2.0395	819.68	-0.0389	0.00017823	0.153
238.33	1.21	1095.7	9.127E-04	122.31	123.42	0.70945	0.9471	2.0404	818.61	-0.0379	0.0001778	0.15282
238.48	1.2163	1095.1	9.132E-04	122.61	123.72	0.71068	0.94694	2.0413	817.54	-0.0369	0.00017737	0.15264
238.62	1.2225	1094.5	9.136E-04	122.9	124.01	0.71191	0.94679	2.0422	816.48	-0.036	0.00017694	0.15246
238.77	1.2287	1093.9	9.141E-04	123.19	124.31	0.71313	0.94663	2.0431	815.41	-0.035	0.00017652	0.15228
238.91	1.235	1093.3	9.146E-04	123.48	124.61	0.71436	0.94648	2.044	814.34	-0.034	0.00017609	0.15209
239.06	1.2413	1092.7	9.151E-04	123.77	124.91	0.71558	0.94633	2.0449	813.27	-0.033	0.00017567	0.15191
239.21	1.2476	1092.1	9.156E-04	124.07	125.21	0.71681	0.94618	2.0458	812.21	-0.032	0.00017524	0.15173
239.35	1.254	1091.5	9.161E-04	124.36	125.51	0.71804	0.94602	2.0468	811.14	-0.031	0.00017482	0.15155
239.5	1.2604	1090.9	9.166E-04	124.65	125.81	0.71926	0.94587	2.0477	810.07	-0.03	0.0001744	0.15137
239.64	1.2667	1090.3	9.172E-04	124.94	126.11	0.72048	0.94572	2.0487	809	-0.029	0.00017398	0.15119
239.79	1.2732	1089.7	9.177E-04	125.24	126.41	0.72171	0.94557	2.0496	807.93	-0.0279	0.00017356	0.15101
239.93	1.2796	1089.1	9.182E-04	125.53	126.7	0.72293	0.94542	2.0506	806.86	-0.0269	0.00017315	0.15083

240.08	1.2861	1088.5	9.187E-04	125.82	127	0.72416	0.94527	2.0515	805.79	-0.0259	0.00017273	0.15065
240.23	1.2926	1087.9	9.192E-04	126.12	127.3	0.72538	0.94512	2.0525	804.72	-0.0249	0.00017232	0.15047
240.37	1.2991	1087.3	9.197E-04	126.41	127.6	0.7266	0.94497	2.0535	803.65	-0.0238	0.0001719	0.15029
240.52	1.3056	1086.7	9.202E-04	126.7	127.9	0.72782	0.94483	2.0544	802.57	-0.0228	0.00017149	0.1501
240.66	1.3122	1086.1	9.207E-04	127	128.2	0.72905	0.94468	2.0554	801.5	-0.0217	0.00017108	0.14992
240.81	1.3188	1085.5	9.212E-04	127.29	128.5	0.73027	0.94453	2.0564	800.43	-0.0207	0.00017067	0.14974
240.96	1.3254	1084.9	9.217E-04	127.58	128.8	0.73149	0.94438	2.0574	799.36	-0.0196	0.00017026	0.14956
241.1	1.332	1084.3	9.223E-04	127.88	129.11	0.73271	0.94424	2.0584	798.28	-0.0185	0.00016985	0.14938
241.25	1.3387	1083.7	9.228E-04	128.17	129.41	0.73393	0.94409	2.0594	797.21	-0.0175	0.00016944	0.1492
241.39	1.3454	1083.1	9.233E-04	128.46	129.71	0.73515	0.94395	2.0604	796.14	-0.0164	0.00016903	0.14902
241.54	1.3521	1082.5	9.238E-04	128.76	130.01	0.73637	0.9438	2.0614	795.06	-0.0153	0.00016863	0.14884
241.69	1.3588	1081.9	9.243E-04	129.05	130.31	0.73759	0.94366	2.0624	793.99	-0.0142	0.00016822	0.14866
241.83	1.3656	1081.3	9.248E-04	129.35	130.61	0.73881	0.94352	2.0635	792.91	-0.0132	0.00016782	0.14848
241.98	1.3723	1080.7	9.254E-04	129.64	130.91	0.74003	0.94337	2.0645	791.83	-0.0121	0.00016742	0.1483
242.12	1.3791	1080	9.259E-04	129.94	131.21	0.74125	0.94323	2.0656	790.76	-0.011	0.00016701	0.14812
242.27	1.386	1079.4	9.264E-04	130.23	131.51	0.74247	0.94309	2.0666	789.68	-0.0099	0.00016661	0.14794
242.42	1.3928	1078.8	9.269E-04	130.52	131.82	0.74369	0.94295	2.0677	788.6	-0.0088	0.00016621	0.14776
242.56	1.3997	1078.2	9.275E-04	130.82	132.12	0.74491	0.94281	2.0687	787.53	-0.0076	0.00016581	0.14758
242.71	1.4066	1077.6	9.280E-04	131.11	132.42	0.74613	0.94267	2.0698	786.45	-0.0065	0.00016542	0.1474
242.85	1.4136	1077	9.285E-04	131.41	132.72	0.74735	0.94253	2.0709	785.37	-0.0054	0.00016502	0.14722
243	1.4205	1076.4	9.291E-04	131.7	133.02	0.74856	0.94239	2.0719	784.29	-0.0043	0.00016462	0.14704
243.14	1.4275	1075.8	9.296E-04	132	133.33	0.74978	0.94225	2.073	783.21	-0.0031	0.00016423	0.14686
243.29	1.4345	1075.1	9.301E-04	132.29	133.63	0.751	0.94211	2.0741	782.13	-0.002	0.00016384	0.14668
243.44	1.4415	1074.5	9.307E-04	132.59	133.93	0.75221	0.94197	2.0752	781.05	-0.0008	0.00016344	0.1465
243.58	1.4486	1073.9	9.312E-04	132.89	134.23	0.75343	0.94184	2.0763	779.97	0.00031	0.00016305	0.14632
243.73	1.4557	1073.3	9.317E-04	133.18	134.54	0.75465	0.9417	2.0774	778.89	0.00147	0.00016266	0.14614
243.87	1.4628	1072.7	9.323E-04	133.48	134.84	0.75586	0.94156	2.0785	777.81	0.00264	0.00016227	0.14597
244.02	1.4699	1072	9.328E-04	133.77	135.14	0.75708	0.94143	2.0797	776.72	0.0038	0.00016188	0.14579
244.17	1.4771	1071.4	9.333E-04	134.07	135.45	0.7583	0.94129	2.0808	775.64	0.00498	0.00016149	0.14561
244.31	1.4843	1070.8	9.339E-04	134.36	135.75	0.75951	0.94116	2.0819	774.56	0.00616	0.00016111	0.14543
244.46	1.4915	1070.2	9.344E-04	134.66	136.05	0.76073	0.94103	2.0831	773.47	0.00735	0.00016072	0.14525
244.6	1.4987	1069.6	9.350E-04	134.96	136.36	0.76194	0.94089	2.0842	772.39	0.00854	0.00016034	0.14507
244.75	1.506	1068.9	9.355E-04	135.25	136.66	0.76316	0.94076	2.0854	771.3	0.00974	0.00015995	0.14489
244.9	1.5133	1068.3	9.361E-04	135.55	136.97	0.76437	0.94063	2.0866	770.21	0.01094	0.00015957	0.14471
245.04	1.5206	1067.7	9.366E-04	135.85	137.27	0.76558	0.9405	2.0877	769.13	0.01215	0.00015919	0.14453
245.19	1.5279	1067.1	9.372E-04	136.14	137.58	0.7668	0.94037	2.0889	768.04	0.01337	0.00015881	0.14435
245.33	1.5353	1066.4	9.377E-04	136.44	137.88	0.76801	0.94024	2.0901	766.95	0.01459	0.00015843	0.14417
245.48	1.5427	1065.8	9.383E-04	136.74	138.18	0.76923	0.94011	2.0913	765.86	0.01582	0.00015805	0.14399
245.62	1.5501	1065.2	9.388E-04	137.03	138.49	0.77044	0.93998	2.0925	764.78	0.01705	0.00015767	0.14382
245.77	1.5576	1064.6	9.394E-04	137.33	138.79	0.77165	0.93985	2.0937	763.69	0.01829	0.00015729	0.14364
245.92	1.565	1063.9	9.399E-04	137.63	139.1	0.77287	0.93972	2.0949	762.6	0.01954	0.00015691	0.14346

246.06	1.5725	1063.3	9.405E-04	137.93	139.41	0.77408	0.9396	2.0961	761.5	0.02079	0.00015654	0.14328
246.21	1.5801	1062.7	9.410E-04	138.22	139.71	0.77529	0.93947	2.0974	760.41	0.02205	0.00015616	0.1431
246.35	1.5876	1062	9.416E-04	138.52	140.02	0.7765	0.93934	2.0986	759.32	0.02331	0.00015579	0.14292
246.5	1.5952	1061.4	9.422E-04	138.82	140.32	0.77772	0.93922	2.0999	758.23	0.02458	0.00015542	0.14274
246.65	1.6028	1060.8	9.427E-04	139.12	140.63	0.77893	0.9391	2.1011	757.13	0.02586	0.00015505	0.14256
246.79	1.6104	1060.1	9.433E-04	139.42	140.93	0.78014	0.93897	2.1024	756.04	0.02715	0.00015467	0.14239
246.94	1.6181	1059.5	9.439E-04	139.71	141.24	0.78135	0.93885	2.1036	754.95	0.02844	0.0001543	0.14221
247.08	1.6258	1058.9	9.444E-04	140.01	141.55	0.78256	0.93873	2.1049	753.85	0.02973	0.00015393	0.14203
247.23	1.6335	1058.2	9.450E-04	140.31	141.85	0.78378	0.9386	2.1062	752.75	0.03104	0.00015357	0.14185
247.38	1.6412	1057.6	9.456E-04	140.61	142.16	0.78499	0.93848	2.1075	751.66	0.03235	0.0001532	0.14167
247.52	1.649	1056.9	9.461E-04	140.91	142.47	0.7862	0.93836	2.1088	750.56	0.03366	0.00015283	0.14149
247.67	1.6568	1056.3	9.467E-04	141.21	142.78	0.78741	0.93824	2.1101	749.46	0.03499	0.00015247	0.14132
247.81	1.6646	1055.7	9.473E-04	141.51	143.08	0.78862	0.93812	2.1114	748.36	0.03632	0.0001521	0.14114
247.96	1.6724	1055	9.479E-04	141.81	143.39	0.78983	0.93801	2.1127	747.26	0.03765	0.00015174	0.14096
248.11	1.6803	1054.4	9.484E-04	142.1	143.7	0.79104	0.93789	2.114	746.16	0.039	0.00015137	0.14078
248.25	1.6882	1053.7	9.490E-04	142.4	144.01	0.79225	0.93777	2.1154	745.06	0.04035	0.00015101	0.1406
248.4	1.6961	1053.1	9.496E-04	142.7	144.31	0.79346	0.93766	2.1167	743.96	0.0417	0.00015065	0.14043
248.54	1.7041	1052.5	9.502E-04	143	144.62	0.79467	0.93754	2.1181	742.85	0.04307	0.00015029	0.14025
248.69	1.7121	1051.8	9.507E-04	143.3	144.93	0.79588	0.93743	2.1194	741.75	0.04444	0.00014993	0.14007
248.83	1.7201	1051.2	9.513E-04	143.6	145.24	0.79709	0.93731	2.1208	740.64	0.04582	0.00014957	0.13989
248.98	1.7281	1050.5	9.519E-04	143.9	145.55	0.7983	0.9372	2.1222	739.54	0.0472	0.00014921	0.13971
249.13	1.7362	1049.9	9.525E-04	144.2	145.86	0.79951	0.93709	2.1236	738.43	0.0486	0.00014886	0.13954
249.27	1.7443	1049.2	9.531E-04	144.5	146.17	0.80072	0.93698	2.125	737.32	0.05	0.0001485	0.13936
249.42	1.7524	1048.6	9.537E-04	144.8	146.48	0.80193	0.93687	2.1264	736.21	0.0514	0.00014814	0.13918
249.56	1.7605	1047.9	9.543E-04	145.1	146.78	0.80314	0.93676	2.1278	735.1	0.05282	0.00014779	0.139
249.71	1.7687	1047.3	9.549E-04	145.41	147.09	0.80435	0.93665	2.1292	733.99	0.05424	0.00014744	0.13882
249.86	1.7769	1046.6	9.555E-04	145.71	147.4	0.80556	0.93654	2.1306	732.88	0.05567	0.00014708	0.13865
250	1.7851	1046	9.561E-04	146.01	147.71	0.80676	0.93643	2.1321	731.77	0.0571	0.00014673	0.13847
250.15	1.7934	1045.3	9.567E-04	146.31	148.02	0.80797	0.93633	2.1335	730.66	0.05855	0.00014638	0.13829
250.29	1.8017	1044.7	9.573E-04	146.61	148.33	0.80918	0.93622	2.135	729.54	0.06	0.00014603	0.13811
250.44	1.81	1044	9.579E-04	146.91	148.64	0.81039	0.93612	2.1364	728.43	0.06146	0.00014568	0.13794
250.59	1.8183	1043.3	9.585E-04	147.21	148.96	0.8116	0.93601	2.1379	727.31	0.06292	0.00014533	0.13776
250.73	1.8267	1042.7	9.591E-04	147.51	149.27	0.81281	0.93591	2.1394	726.2	0.0644	0.00014498	0.13758
250.88	1.8351	1042	9.597E-04	147.82	149.58	0.81401	0.93581	2.1409	725.08	0.06588	0.00014464	0.1374
251.02	1.8435	1041.4	9.603E-04	148.12	149.89	0.81522	0.93571	2.1424	723.96	0.06737	0.00014429	0.13723
251.17	1.852	1040.7	9.609E-04	148.42	150.2	0.81643	0.93561	2.1439	722.84	0.06887	0.00014394	0.13705
251.31	1.8605	1040.1	9.615E-04	148.72	150.51	0.81764	0.93551	2.1454	721.72	0.07037	0.0001436	0.13687
251.46	1.869	1039.4	9.621E-04	149.03	150.82	0.81885	0.93541	2.1469	720.6	0.07189	0.00014325	0.13669
251.61	1.8775	1038.7	9.627E-04	149.33	151.14	0.82005	0.93532	2.1485	719.47	0.07341	0.00014291	0.13652
251.75	1.8861	1038.1	9.633E-04	149.63	151.45	0.82126	0.93522	2.15	718.35	0.07494	0.00014257	0.13634
251.9	1.8947	1037.4	9.640E-04	149.93	151.76	0.82247	0.93513	2.1516	717.22	0.07648	0.00014223	0.13616

252.04	1.9033	1036.7	9.646E-04	150.24	152.07	0.82368	0.93503	2.1531	716.1	0.07802	0.00014189	0.13598
252.19	1.912	1036.1	9.652E-04	150.54	152.39	0.82488	0.93494	2.1547	714.97	0.07958	0.00014155	0.13581
252.34	1.9206	1035.4	9.658E-04	150.84	152.7	0.82609	0.93485	2.1563	713.84	0.08114	0.00014121	0.13563
252.48	1.9294	1034.7	9.664E-04	151.15	153.01	0.8273	0.93476	2.1579	712.71	0.08271	0.00014087	0.13545
252.63	1.9381	1034.1	9.671E-04	151.45	153.32	0.82851	0.93467	2.1595	711.58	0.08429	0.00014053	0.13528
252.77	1.9469	1033.4	9.677E-04	151.75	153.64	0.82971	0.93459	2.1611	710.45	0.08588	0.00014019	0.1351
252.92	1.9557	1032.7	9.683E-04	152.06	153.95	0.83092	0.9345	2.1627	709.32	0.08747	0.00013986	0.13492
253.07	1.9645	1032	9.690E-04	152.36	154.27	0.83213	0.93441	2.1644	708.18	0.08908	0.00013952	0.13474
253.21	1.9734	1031.4	9.696E-04	152.67	154.58	0.83333	0.93433	2.166	707.04	0.09069	0.00013919	0.13457
253.36	1.9822	1030.7	9.702E-04	152.97	154.89	0.83454	0.93425	2.1677	705.91	0.09232	0.00013885	0.13439
253.5	1.9912	1030	9.709E-04	153.28	155.21	0.83575	0.93417	2.1693	704.77	0.09395	0.00013852	0.13421
253.65	2.0001	1029.4	9.715E-04	153.58	155.52	0.83696	0.93409	2.171	703.63	0.09559	0.00013819	0.13404
253.79	2.0091	1028.7	9.721E-04	153.89	155.84	0.83816	0.93401	2.1727	702.49	0.09724	0.00013786	0.13386
253.94	2.0181	1028	9.728E-04	154.19	156.15	0.83937	0.93393	2.1744	701.35	0.09889	0.00013753	0.13368
254.09	2.0271	1027.3	9.734E-04	154.5	156.47	0.84058	0.93386	2.1761	700.2	0.10056	0.0001372	0.13351
254.23	2.0362	1026.6	9.741E-04	154.8	156.79	0.84178	0.93378	2.1778	699.06	0.10224	0.00013687	0.13333
254.38	2.0453	1026	9.747E-04	155.11	157.1	0.84299	0.93371	2.1795	697.91	0.10392	0.00013654	0.13315
254.52	2.0544	1025.3	9.754E-04	155.41	157.42	0.8442	0.93364	2.1813	696.76	0.10562	0.00013621	0.13297
254.67	2.0635	1024.6	9.760E-04	155.72	157.73	0.84541	0.93357	2.183	695.62	0.10732	0.00013588	0.1328
254.82	2.0727	1023.9	9.767E-04	156.03	158.05	0.84661	0.9335	2.1848	694.46	0.10904	0.00013556	0.13262
254.96	2.0819	1023.2	9.773E-04	156.33	158.37	0.84782	0.93343	2.1866	693.31	0.11076	0.00013523	0.13244
255.11	2.0912	1022.5	9.780E-04	156.64	158.68	0.84903	0.93337	2.1884	692.16	0.11249	0.0001349	0.13227
255.25	2.1004	1021.8	9.786E-04	156.94	159	0.85023	0.9333	2.1901	691.01	0.11423	0.00013458	0.13209
255.4	2.1097	1021.2	9.793E-04	157.25	159.32	0.85144	0.93324	2.192	689.85	0.11599	0.00013426	0.13191
255.55	2.1191	1020.5	9.799E-04	157.56	159.64	0.85265	0.93318	2.1938	688.69	0.11775	0.00013393	0.13174
255.69	2.1284	1019.8	9.806E-04	157.87	159.95	0.85385	0.93312	2.1956	687.53	0.11952	0.00013361	0.13156
255.84	2.1378	1019.1	9.813E-04	158.17	160.27	0.85506	0.93306	2.1974	686.37	0.1213	0.00013329	0.13138
255.98	2.1473	1018.4	9.819E-04	158.48	160.59	0.85627	0.93301	2.1993	685.21	0.12309	0.00013297	0.13121
256.13	2.1567	1017.7	9.826E-04	158.79	160.91	0.85748	0.93296	2.2012	684.05	0.12489	0.00013265	0.13103
256.28	2.1662	1017	9.833E-04	159.1	161.23	0.85868	0.9329	2.203	682.88	0.1267	0.00013233	0.13085
256.42	2.1757	1016.3	9.840E-04	159.4	161.55	0.85989	0.93285	2.2049	681.72	0.12853	0.00013201	0.13068
256.57	2.1852	1015.6	9.846E-04	159.71	161.86	0.8611	0.93281	2.2068	680.55	0.13036	0.00013169	0.1305
256.71	2.1948	1014.9	9.853E-04	160.02	162.18	0.86231	0.93276	2.2087	679.38	0.1322	0.00013138	0.13032
256.86	2.2044	1014.2	9.860E-04	160.33	162.5	0.86351	0.93271	2.2107	678.21	0.13405	0.00013106	0.13015
257	2.2141	1013.5	9.867E-04	160.64	162.82	0.86472	0.93267	2.2126	677.03	0.13592	0.00013074	0.12997
257.15	2.2237	1012.8	9.873E-04	160.95	163.14	0.86593	0.93263	2.2146	675.86	0.13779	0.00013043	0.12979
257.3	2.2334	1012.1	9.880E-04	161.26	163.46	0.86714	0.93259	2.2165	674.68	0.13967	0.00013011	0.12962
257.44	2.2432	1011.4	9.887E-04	161.57	163.78	0.86834	0.93256	2.2185	673.51	0.14157	0.0001298	0.12944
257.59	2.2529	1010.7	9.894E-04	161.88	164.1	0.86955	0.93252	2.2205	672.33	0.14347	0.00012949	0.12927
257.73	2.2627	1010	9.901E-04	162.19	164.43	0.87076	0.93249	2.2225	671.15	0.14539	0.00012917	0.12909
257.88	2.2725	1009.3	9.908E-04	162.49	164.75	0.87197	0.93246	2.2245	669.96	0.14732	0.00012886	0.12891

258.03	2.2824	1008.6	9.915E-04	162.81	165.07	0.87318	0.93243	2.2265	668.78	0.14926	0.00012855	0.12874
258.17	2.2923	1007.9	9.922E-04	163.12	165.39	0.87439	0.9324	2.2286	667.59	0.15121	0.00012824	0.12856
258.32	2.3022	1007.2	9.929E-04	163.43	165.71	0.87559	0.93238	2.2306	666.4	0.15317	0.00012793	0.12838
258.46	2.3121	1006.5	9.936E-04	163.74	166.03	0.8768	0.93236	2.2327	665.22	0.15514	0.00012762	0.12821
258.61	2.3221	1005.7	9.943E-04	164.05	166.36	0.87801	0.93234	2.2348	664.02	0.15713	0.00012731	0.12803
258.76	2.3321	1005	9.950E-04	164.36	166.68	0.87922	0.93232	2.2369	662.83	0.15912	0.000127	0.12785
258.9	2.3421	1004.3	9.957E-04	164.67	167	0.88043	0.93231	2.239	661.64	0.16113	0.0001267	0.12768
259.05	2.3522	1003.6	9.964E-04	164.98	167.32	0.88164	0.93229	2.2411	660.44	0.16315	0.00012639	0.1275
259.19	2.3623	1002.9	9.971E-04	165.29	167.65	0.88285	0.93228	2.2433	659.24	0.16518	0.00012608	0.12732
259.34	2.3725	1002.2	9.979E-04	165.6	167.97	0.88406	0.93228	2.2454	658.04	0.16722	0.00012578	0.12715
259.48	2.3826	1001.4	9.986E-04	165.92	168.3	0.88527	0.93227	2.2476	656.84	0.16928	0.00012547	0.12697
259.63	2.3928	1000.7	9.993E-04	166.23	168.62	0.88648	0.93227	2.2498	655.64	0.17134	0.00012517	0.1268
259.78	2.4031	1000	1.000E-03	166.54	168.94	0.88769	0.93227	2.252	654.43	0.17342	0.00012487	0.12662
259.92	2.4133	999.27	1.001E-03	166.85	169.27	0.8889	0.93227	2.2542	653.23	0.17551	0.00012456	0.12644
260.07	2.4236	998.55	1.002E-03	167.17	169.59	0.89011	0.93227	2.2564	652.02	0.17761	0.00012426	0.12627
260.21	2.4339	997.82	1.002E-03	167.48	169.92	0.89132	0.93228	2.2586	650.81	0.17973	0.00012396	0.12609
260.36	2.4443	997.09	1.003E-03	167.79	170.24	0.89253	0.93229	2.2609	649.59	0.18186	0.00012366	0.12591
260.51	2.4547	996.36	1.004E-03	168.11	170.57	0.89374	0.9323	2.2632	648.38	0.184	0.00012336	0.12574
260.65	2.4651	995.63	1.004E-03	168.42	170.9	0.89495	0.93232	2.2655	647.16	0.18615	0.00012306	0.12556
260.8	2.4756	994.9	1.005E-03	168.73	171.22	0.89616	0.93233	2.2678	645.95	0.18832	0.00012276	0.12539
260.94	2.4861	994.17	1.006E-03	169.05	171.55	0.89737	0.93235	2.2701	644.73	0.1905	0.00012246	0.12521
261.09	2.4966	993.44	1.007E-03	169.36	171.88	0.89858	0.93238	2.2724	643.5	0.19269	0.00012216	0.12503
261.24	2.5071	992.7	1.007E-03	169.68	172.2	0.89979	0.9324	2.2748	642.28	0.1949	0.00012187	0.12486
261.38	2.5177	991.96	1.008E-03	169.99	172.53	0.90101	0.93243	2.2771	641.06	0.19711	0.00012157	0.12468
261.53	2.5283	991.23	1.009E-03	170.31	172.86	0.90222	0.93246	2.2795	639.83	0.19935	0.00012127	0.1245
261.67	2.539	990.49	1.010E-03	170.62	173.19	0.90343	0.9325	2.2819	638.6	0.20159	0.00012098	0.12433
261.82	2.5497	989.75	1.010E-03	170.94	173.51	0.90464	0.93253	2.2844	637.37	0.20385	0.00012068	0.12415
261.96	2.5604	989	1.011E-03	171.25	173.84	0.90585	0.93257	2.2868	636.14	0.20612	0.00012039	0.12398
262.11	2.5711	988.26	1.012E-03	171.57	174.17	0.90707	0.93262	2.2892	634.9	0.20841	0.0001201	0.1238
262.26	2.5819	987.52	1.013E-03	171.89	174.5	0.90828	0.93266	2.2917	633.67	0.21071	0.0001198	0.12362
262.4	2.5927	986.77	1.013E-03	172.2	174.83	0.90949	0.93271	2.2942	632.43	0.21302	0.00011951	0.12345
262.55	2.6036	986.02	1.014E-03	172.52	175.16	0.91071	0.93276	2.2967	631.19	0.21535	0.00011922	0.12327
262.69	2.6145	985.28	1.015E-03	172.84	175.49	0.91192	0.93281	2.2992	629.95	0.2177	0.00011893	0.12309
262.84	2.6254	984.53	1.016E-03	173.15	175.82	0.91314	0.93287	2.3018	628.7	0.22005	0.00011864	0.12292
262.99	2.6363	983.77	1.017E-03	173.47	176.15	0.91435	0.93293	2.3043	627.46	0.22243	0.00011835	0.12274
263.13	2.6473	983.02	1.017E-03	173.79	176.48	0.91557	0.933	2.3069	626.21	0.22481	0.00011806	0.12257
263.28	2.6583	982.27	1.018E-03	174.1	176.81	0.91678	0.93306	2.3095	624.96	0.22721	0.00011777	0.12239
263.42	2.6694	981.51	1.019E-03	174.42	177.14	0.918	0.93313	2.3121	623.71	0.22963	0.00011748	0.12221
263.57	2.6805	980.75	1.020E-03	174.74	177.47	0.91921	0.9332	2.3148	622.45	0.23206	0.00011719	0.12204
263.72	2.6916	980	1.020E-03	175.06	177.81	0.92043	0.93328	2.3174	621.2	0.23451	0.0001169	0.12186
263.86	2.7027	979.24	1.021E-03	175.38	178.14	0.92164	0.93336	2.3201	619.94	0.23697	0.00011662	0.12168

264.01	2.7139	978.47	1.022E-03	175.7	178.47	0.92286	0.93344	2.3228	618.68	0.23945	0.00011633	0.12151
264.15	2.7251	977.71	1.023E-03	176.02	178.8	0.92408	0.93352	2.3255	617.42	0.24194	0.00011604	0.12133
264.3	2.7364	976.95	1.024E-03	176.34	179.14	0.92529	0.93361	2.3282	616.16	0.24445	0.00011576	0.12115
264.45	2.7477	976.18	1.024E-03	176.66	179.47	0.92651	0.9337	2.331	614.9	0.24697	0.00011547	0.12098
264.59	2.759	975.41	1.025E-03	176.97	179.8	0.92773	0.9338	2.3338	613.63	0.24951	0.00011519	0.1208
264.74	2.7704	974.64	1.026E-03	177.3	180.14	0.92895	0.9339	2.3366	612.36	0.25207	0.00011491	0.12063
264.88	2.7817	973.87	1.027E-03	177.62	180.47	0.93017	0.934	2.3394	611.09	0.25464	0.00011462	0.12045
265.03	2.7932	973.1	1.028E-03	177.94	180.81	0.93138	0.9341	2.3422	609.82	0.25723	0.00011434	0.12027
265.17	2.8046	972.33	1.029E-03	178.26	181.14	0.9326	0.93421	2.3451	608.55	0.25983	0.00011406	0.1201
265.32	2.8161	971.55	1.029E-03	178.58	181.48	0.93382	0.93432	2.348	607.27	0.26245	0.00011378	0.11992
265.47	2.8276	970.78	1.030E-03	178.9	181.81	0.93504	0.93443	2.3509	606	0.26509	0.0001135	0.11974
265.61	2.8392	970	1.031E-03	179.22	182.15	0.93626	0.93455	2.3538	604.72	0.26775	0.00011322	0.11957
265.76	2.8508	969.22	1.032E-03	179.54	182.48	0.93748	0.93467	2.3567	603.44	0.27042	0.00011294	0.11939
265.9	2.8624	968.44	1.033E-03	179.87	182.82	0.9387	0.93479	2.3597	602.15	0.27311	0.00011266	0.11921
266.05	2.8741	967.66	1.033E-03	180.19	183.16	0.93993	0.93492	2.3627	600.87	0.27582	0.00011238	0.11904
266.2	2.8858	966.87	1.034E-03	180.51	183.5	0.94115	0.93505	2.3657	599.58	0.27854	0.0001121	0.11886
266.34	2.8975	966.09	1.035E-03	180.83	183.83	0.94237	0.93518	2.3687	598.3	0.28129	0.00011182	0.11869
266.49	2.9093	965.3	1.036E-03	181.16	184.17	0.94359	0.93532	2.3718	597.01	0.28405	0.00011155	0.11851
266.63	2.9211	964.51	1.037E-03	181.48	184.51	0.94482	0.93546	2.3749	595.71	0.28682	0.00011127	0.11833
266.78	2.9329	963.72	1.038E-03	181.8	184.85	0.94604	0.9356	2.378	594.42	0.28962	0.00011099	0.11816
266.93	2.9448	962.93	1.039E-03	182.13	185.19	0.94726	0.93575	2.3811	593.13	0.29244	0.00011072	0.11798
267.07	2.9567	962.13	1.039E-03	182.45	185.53	0.94849	0.9359	2.3843	591.83	0.29527	0.00011044	0.1178
267.22	2.9687	961.34	1.040E-03	182.78	185.87	0.94971	0.93605	2.3875	590.53	0.29812	0.00011017	0.11763
267.36	2.9806	960.54	1.041E-03	183.1	186.21	0.95094	0.93621	2.3907	589.23	0.301	0.00010989	0.11745
267.51	2.9927	959.74	1.042E-03	183.43	186.55	0.95216	0.93637	2.3939	587.93	0.30389	0.00010962	0.11727
267.65	3.0047	958.94	1.043E-03	183.75	186.89	0.95339	0.93653	2.3972	586.63	0.3068	0.00010935	0.1171
267.8	3.0168	958.14	1.044E-03	184.08	187.23	0.95462	0.9367	2.4005	585.32	0.30973	0.00010908	0.11692
267.95	3.0289	957.33	1.045E-03	184.41	187.57	0.95584	0.93687	2.4038	584.02	0.31268	0.0001088	0.11674
268.09	3.0411	956.53	1.045E-03	184.73	187.91	0.95707	0.93704	2.4071	582.71	0.31565	0.00010853	0.11657
268.24	3.0533	955.72	1.046E-03	185.06	188.25	0.9583	0.93721	2.4105	581.4	0.31863	0.00010826	0.11639
268.38	3.0655	954.91	1.047E-03	185.39	188.6	0.95953	0.93739	2.4139	580.09	0.32164	0.00010799	0.11621
268.53	3.0778	954.1	1.048E-03	185.71	188.94	0.96076	0.93758	2.4173	578.78	0.32467	0.00010772	0.11604
268.68	3.0901	953.29	1.049E-03	186.04	189.28	0.96199	0.93776	2.4208	577.46	0.32772	0.00010745	0.11586
268.82	3.1024	952.47	1.050E-03	186.37	189.63	0.96322	0.93795	2.4243	576.14	0.3308	0.00010718	0.11568
268.97	3.1148	951.66	1.051E-03	186.7	189.97	0.96445	0.93814	2.4278	574.83	0.33389	0.00010691	0.11551
269.11	3.1272	950.84	1.052E-03	187.02	190.31	0.96568	0.93834	2.4313	573.51	0.337	0.00010664	0.11533
269.26	3.1396	950.02	1.053E-03	187.35	190.66	0.96691	0.93854	2.4349	572.19	0.34014	0.00010638	0.11515
269.41	3.1521	949.2	1.054E-03	187.68	191	0.96814	0.93874	2.4385	570.86	0.34329	0.00010611	0.11498
269.55	3.1646	948.37	1.054E-03	188.01	191.35	0.96938	0.93894	2.4421	569.54	0.34647	0.00010584	0.1148
269.7	3.1772	947.55	1.055E-03	188.34	191.69	0.97061	0.93915	2.4458	568.22	0.34967	0.00010557	0.11462
269.84	3.1898	946.72	1.056E-03	188.67	192.04	0.97185	0.93936	2.4494	566.89	0.3529	0.00010531	0.11444

269.99	3.2024	945.89	1.057E-03	189	192.39	0.97308	0.93957	2.4532	565.56	0.35614	0.00010504	0.11427
270.13	3.2151	945.06	1.058E-03	189.33	192.73	0.97432	0.93979	2.4569	564.23	0.35941	0.00010478	0.11409
270.28	3.2278	944.22	1.059E-03	189.66	193.08	0.97555	0.94001	2.4607	562.9	0.3627	0.00010451	0.11391
270.43	3.2405	943.39	1.060E-03	189.99	193.43	0.97679	0.94023	2.4645	561.57	0.36602	0.00010425	0.11374
270.57	3.2533	942.55	1.061E-03	190.33	193.78	0.97803	0.94046	2.4684	560.23	0.36936	0.00010399	0.11356
270.72	3.2661	941.71	1.062E-03	190.66	194.13	0.97926	0.94069	2.4723	558.9	0.37272	0.00010372	0.11338
270.86	3.2789	940.87	1.063E-03	190.99	194.48	0.9805	0.94092	2.4762	557.56	0.37611	0.00010346	0.11321
271.01	3.2918	940.03	1.064E-03	191.32	194.83	0.98174	0.94116	2.4801	556.22	0.37952	0.0001032	0.11303
271.16	3.3048	939.18	1.065E-03	191.66	195.18	0.98298	0.94139	2.4841	554.88	0.38295	0.00010293	0.11285
271.3	3.3177	938.34	1.066E-03	191.99	195.53	0.98422	0.94163	2.4881	553.54	0.38641	0.00010267	0.11267
271.45	3.3307	937.49	1.067E-03	192.32	195.88	0.98546	0.94188	2.4922	552.2	0.3899	0.00010241	0.1125
271.59	3.3437	936.64	1.068E-03	192.66	196.23	0.98671	0.94213	2.4963	550.86	0.39341	0.00010215	0.11232
271.74	3.3568	935.79	1.069E-03	192.99	196.58	0.98795	0.94237	2.5004	549.51	0.39694	0.00010189	0.11214
271.89	3.3699	934.93	1.070E-03	193.33	196.93	0.98919	0.94263	2.5046	548.16	0.4005	0.00010163	0.11196
272.03	3.3831	934.07	1.071E-03	193.66	197.28	0.99044	0.94288	2.5088	546.82	0.40409	0.00010137	0.11179
272.18	3.3963	933.21	1.072E-03	194	197.64	0.99168	0.94314	2.513	545.47	0.40771	0.00010111	0.11161
272.32	3.4095	932.35	1.073E-03	194.33	197.99	0.99293	0.9434	2.5173	544.12	0.41135	0.00010085	0.11143
272.47	3.4228	931.49	1.074E-03	194.67	198.34	0.99417	0.94366	2.5216	542.77	0.41501	0.00010059	0.11125
272.62	3.4361	930.62	1.075E-03	195.01	198.7	0.99542	0.94393	2.526	541.41	0.41871	0.00010034	0.11108
272.76	3.4494	929.76	1.076E-03	195.34	199.05	0.99667	0.9442	2.5304	540.06	0.42243	0.00010008	0.1109
272.91	3.4628	928.89	1.077E-03	195.68	199.41	0.99792	0.94447	2.5348	538.7	0.42618	9.98E-05	0.11072
273.05	3.4762	928.01	1.078E-03	196.02	199.76	0.99917	0.94475	2.5393	537.35	0.42996	9.96E-05	0.11054
273.2	3.4896	927.14	1.079E-03	196.36	200.12	1.0004	0.94502	2.5438	535.99	0.43377	9.93E-05	0.11037
273.34	3.5031	926.26	1.080E-03	196.69	200.48	1.0017	0.9453	2.5484	534.63	0.4376	9.91E-05	0.11019
273.49	3.5167	925.38	1.081E-03	197.03	200.83	1.0029	0.94558	2.553	533.27	0.44147	9.88E-05	0.11001
273.64	3.5302	924.5	1.082E-03	197.37	201.19	1.0042	0.94587	2.5576	531.91	0.44536	9.85E-05	0.10983
273.78	3.5438	923.62	1.083E-03	197.71	201.55	1.0054	0.94616	2.5623	530.55	0.44928	9.83E-05	0.10966
273.93	3.5575	922.73	1.084E-03	198.05	201.91	1.0067	0.94645	2.5671	529.19	0.45324	9.80E-05	0.10948
274.07	3.5712	921.85	1.085E-03	198.39	202.27	1.0079	0.94674	2.5719	527.82	0.45722	9.78E-05	0.1093
274.22	3.5849	920.96	1.086E-03	198.73	202.62	1.0092	0.94703	2.5767	526.46	0.46124	9.75E-05	0.10912
274.37	3.5987	920.06	1.087E-03	199.07	202.98	1.0105	0.94733	2.5816	525.09	0.46528	9.73E-05	0.10894
274.51	3.6125	919.17	1.088E-03	199.41	203.34	1.0117	0.94763	2.5865	523.72	0.46936	9.70E-05	0.10877
274.66	3.6263	918.27	1.089E-03	199.76	203.71	1.013	0.94793	2.5915	522.35	0.47347	9.68E-05	0.10859
274.8	3.6402	917.37	1.090E-03	200.1	204.07	1.0142	0.94824	2.5965	520.98	0.47761	9.65E-05	0.10841
274.95	3.6541	916.47	1.091E-03	200.44	204.43	1.0155	0.94854	2.6016	519.61	0.48179	9.63E-05	0.10823
275.1	3.668	915.57	1.092E-03	200.78	204.79	1.0168	0.94885	2.6067	518.24	0.48599	9.60E-05	0.10805
275.24	3.682	914.66	1.093E-03	201.13	205.15	1.018	0.94916	2.6119	516.87	0.49023	9.58E-05	0.10787
275.39	3.6961	913.75	1.094E-03	201.47	205.52	1.0193	0.94948	2.6171	515.49	0.49451	9.55E-05	0.1077
275.53	3.7102	912.84	1.096E-03	201.82	205.88	1.0205	0.94979	2.6224	514.12	0.49882	9.53E-05	0.10752
275.68	3.7243	911.92	1.097E-03	202.16	206.25	1.0218	0.95011	2.6277	512.74	0.50316	9.50E-05	0.10734
275.82	3.7384	911.01	1.098E-03	202.51	206.61	1.0231	0.95043	2.6331	511.36	0.50754	9.48E-05	0.10716

275.97	3.7526	910.09	1.099E-03	202.85	206.98	1.0243	0.95075	2.6385	509.99	0.51195	9.45E-05	0.10698
276.12	3.7669	909.16	1.100E-03	203.2	207.34	1.0256	0.95108	2.644	508.61	0.5164	9.43E-05	0.1068
276.26	3.7811	908.24	1.101E-03	203.55	207.71	1.0269	0.9514	2.6495	507.23	0.52088	9.40E-05	0.10662
276.41	3.7955	907.31	1.102E-03	203.89	208.08	1.0282	0.95173	2.6552	505.85	0.5254	9.38E-05	0.10645
276.55	3.8098	906.38	1.103E-03	204.24	208.44	1.0294	0.95206	2.6608	504.46	0.52996	9.35E-05	0.10627
276.7	3.8242	905.45	1.104E-03	204.59	208.81	1.0307	0.9524	2.6665	503.08	0.53456	9.33E-05	0.10609
276.85	3.8386	904.51	1.106E-03	204.94	209.18	1.032	0.95273	2.6723	501.7	0.53919	9.30E-05	0.10591
276.99	3.8531	903.57	1.107E-03	205.29	209.55	1.0333	0.95307	2.6782	500.31	0.54386	9.28E-05	0.10573
277.14	3.8676	902.63	1.108E-03	205.63	209.92	1.0345	0.95341	2.6841	498.92	0.54857	9.25E-05	0.10555
277.28	3.8822	901.69	1.109E-03	205.98	210.29	1.0358	0.95375	2.69	497.54	0.55332	9.23E-05	0.10537
277.43	3.8968	900.74	1.110E-03	206.33	210.66	1.0371	0.95409	2.6961	496.15	0.55811	9.20E-05	0.10519
277.58	3.9114	899.79	1.111E-03	206.69	211.03	1.0384	0.95444	2.7022	494.76	0.56294	9.18E-05	0.10501
277.72	3.9261	898.84	1.113E-03	207.04	211.4	1.0397	0.95478	2.7083	493.37	0.56781	9.15E-05	0.10483
277.87	3.9408	897.89	1.114E-03	207.39	211.78	1.0409	0.95513	2.7146	491.98	0.57272	9.13E-05	0.10465
278.01	3.9556	896.93	1.115E-03	207.74	212.15	1.0422	0.95548	2.7209	490.59	0.57768	9.10E-05	0.10448
278.16	3.9704	895.97	1.116E-03	208.09	212.52	1.0435	0.95584	2.7272	489.2	0.58267	9.08E-05	0.1043
278.31	3.9852	895	1.117E-03	208.45	212.9	1.0448	0.95619	2.7337	487.8	0.58771	9.06E-05	0.10412
278.45	4.0001	894.04	1.119E-03	208.8	213.27	1.0461	0.95655	2.7402	486.41	0.5928	9.03E-05	0.10394
278.6	4.015	893.07	1.120E-03	209.15	213.65	1.0474	0.95691	2.7468	485.01	0.59792	9.01E-05	0.10376
278.74	4.03	892.1	1.121E-03	209.51	214.03	1.0487	0.95727	2.7534	483.62	0.60309	8.98E-05	0.10358
278.89	4.045	891.12	1.122E-03	209.87	214.4	1.05	0.95763	2.7602	482.22	0.60831	8.96E-05	0.1034
279.03	4.0601	890.14	1.123E-03	210.22	214.78	1.0512	0.958	2.767	480.82	0.61357	8.93E-05	0.10322
279.18	4.0752	889.16	1.125E-03	210.58	215.16	1.0525	0.95836	2.7739	479.42	0.61888	8.91E-05	0.10304
279.33	4.0903	888.17	1.126E-03	210.93	215.54	1.0538	0.95873	2.7809	478.02	0.62423	8.89E-05	0.10286
279.47	4.1055	887.19	1.127E-03	211.29	215.92	1.0551	0.9591	2.7879	476.62	0.62964	8.86E-05	0.10268
279.62	4.1207	886.19	1.128E-03	211.65	216.3	1.0564	0.95947	2.795	475.22	0.63509	8.84E-05	0.1025
279.76	4.136	885.2	1.130E-03	212.01	216.68	1.0577	0.95985	2.8023	473.81	0.64058	8.81E-05	0.10232
279.91	4.1513	884.2	1.131E-03	212.37	217.06	1.059	0.96022	2.8096	472.41	0.64613	8.79E-05	0.10214
280.06	4.1666	883.2	1.132E-03	212.73	217.44	1.0603	0.9606	2.817	471.01	0.65173	8.76E-05	0.10196
280.2	4.182	882.2	1.134E-03	213.09	217.83	1.0616	0.96098	2.8244	469.6	0.65738	8.74E-05	0.10178
280.35	4.1974	881.19	1.135E-03	213.45	218.21	1.063	0.96137	2.832	468.19	0.66308	8.72E-05	0.1016
280.49	4.2129	880.18	1.136E-03	213.81	218.6	1.0643	0.96175	2.8397	466.79	0.66883	8.69E-05	0.10142
280.64	4.2284	879.16	1.137E-03	214.17	218.98	1.0656	0.96214	2.8474	465.38	0.67464	8.67E-05	0.10124
280.79	4.244	878.14	1.139E-03	214.53	219.37	1.0669	0.96252	2.8553	463.97	0.68049	8.64E-05	0.10106
280.93	4.2596	877.12	1.140E-03	214.9	219.75	1.0682	0.96292	2.8632	462.56	0.68641	8.62E-05	0.10087
281.08	4.2752	876.1	1.141E-03	215.26	220.14	1.0695	0.96331	2.8713	461.14	0.69237	8.60E-05	0.10069
281.22	4.2909	875.07	1.143E-03	215.63	220.53	1.0708	0.9637	2.8794	459.73	0.6984	8.57E-05	0.10051
281.37	4.3066	874.03	1.144E-03	215.99	220.92	1.0721	0.9641	2.8877	458.32	0.70448	8.55E-05	0.10033
281.51	4.3224	873	1.146E-03	216.36	221.31	1.0735	0.9645	2.896	456.9	0.71061	8.52E-05	0.10015
281.66	4.3382	871.96	1.147E-03	216.72	221.7	1.0748	0.9649	2.9045	455.49	0.71681	8.50E-05	0.099971
281.81	4.3541	870.91	1.148E-03	217.09	222.09	1.0761	0.9653	2.9131	454.07	0.72306	8.48E-05	0.09979

281.95	4.37	869.87	1.150E-03	217.46	222.48	1.0774	0.96571	2.9218	452.65	0.72937	8.45E-05	0.099608
282.1	4.3859	868.81	1.151E-03	217.83	222.87	1.0788	0.96612	2.9306	451.23	0.73575	8.43E-05	0.099427
282.24	4.4019	867.76	1.152E-03	218.2	223.27	1.0801	0.96653	2.9395	449.81	0.74218	8.40E-05	0.099246
282.39	4.418	866.7	1.154E-03	218.56	223.66	1.0814	0.96694	2.9485	448.39	0.74868	8.38E-05	0.099065
282.54	4.434	865.64	1.155E-03	218.94	224.06	1.0828	0.96735	2.9577	446.97	0.75524	8.36E-05	0.098883
282.68	4.4502	864.57	1.157E-03	219.31	224.45	1.0841	0.96777	2.967	445.55	0.76186	8.33E-05	0.098702
282.83	4.4663	863.5	1.158E-03	219.68	224.85	1.0854	0.96819	2.9764	444.12	0.76855	8.31E-05	0.09852
282.97	4.4825	862.43	1.160E-03	220.05	225.25	1.0868	0.96861	2.9859	442.69	0.77531	8.28E-05	0.098339
283.12	4.4988	861.35	1.161E-03	220.42	225.65	1.0881	0.96904	2.9956	441.27	0.78213	8.26E-05	0.098157
283.27	4.5151	860.26	1.162E-03	220.8	226.05	1.0895	0.96947	3.0054	439.84	0.78902	8.24E-05	0.097975
283.41	4.5314	859.18	1.164E-03	221.17	226.45	1.0908	0.9699	3.0153	438.41	0.79598	8.21E-05	0.097793
283.56	4.5478	858.08	1.165E-03	221.55	226.85	1.0921	0.97033	3.0254	436.98	0.803	8.19E-05	0.097612
283.7	4.5642	856.99	1.167E-03	221.92	227.25	1.0935	0.97077	3.0356	435.55	0.8101	8.17E-05	0.09743
283.85	4.5807	855.89	1.168E-03	222.3	227.65	1.0949	0.97121	3.046	434.11	0.81727	8.14E-05	0.097248
283.99	4.5972	854.78	1.170E-03	222.68	228.06	1.0962	0.97165	3.0565	432.68	0.82452	8.12E-05	0.097066
284.14	4.6138	853.67	1.171E-03	223.06	228.46	1.0976	0.97209	3.0672	431.24	0.83184	8.09E-05	0.096883
284.29	4.6304	852.56	1.173E-03	223.43	228.87	1.0989	0.97254	3.078	429.8	0.83923	8.07E-05	0.096701
284.43	4.6471	851.44	1.175E-03	223.81	229.27	1.1003	0.97299	3.089	428.37	0.8467	8.05E-05	0.096519
284.58	4.6638	850.32	1.176E-03	224.2	229.68	1.1016	0.97345	3.1001	426.93	0.85425	8.02E-05	0.096337
284.72	4.6805	849.19	1.178E-03	224.58	230.09	1.103	0.9739	3.1114	425.48	0.86187	8.00E-05	0.096154
284.87	4.6973	848.06	1.179E-03	224.96	230.5	1.1044	0.97437	3.1229	424.04	0.86958	7.98E-05	0.095972
285.02	4.7142	846.92	1.181E-03	225.34	230.91	1.1057	0.97483	3.1346	422.6	0.87737	7.95E-05	0.095789
285.16	4.7311	845.78	1.182E-03	225.73	231.32	1.1071	0.9753	3.1464	421.15	0.88524	7.93E-05	0.095607
285.31	4.748	844.63	1.184E-03	226.11	231.73	1.1085	0.97577	3.1584	419.7	0.89319	7.90E-05	0.095424
285.45	4.765	843.48	1.186E-03	226.5	232.15	1.1099	0.97625	3.1706	418.25	0.90123	7.88E-05	0.095242
285.6	4.782	842.32	1.187E-03	226.88	232.56	1.1113	0.97673	3.183	416.8	0.90936	7.86E-05	0.095059
285.75	4.7991	841.16	1.189E-03	227.27	232.98	1.1126	0.97721	3.1956	415.35	0.91757	7.83E-05	0.094876
285.89	4.8162	839.99	1.191E-03	227.66	233.39	1.114	0.9777	3.2084	413.89	0.92587	7.81E-05	0.094694
286.04	4.8333	838.82	1.192E-03	228.05	233.81	1.1154	0.97819	3.2214	412.43	0.93427	7.79E-05	0.094511
286.18	4.8505	837.64	1.194E-03	228.44	234.23	1.1168	0.97869	3.2346	410.98	0.94276	7.76E-05	0.094328
286.33	4.8678	836.46	1.196E-03	228.83	234.65	1.1182	0.97919	3.2481	409.52	0.95134	7.74E-05	0.094145
286.48	4.8851	835.27	1.197E-03	229.22	235.07	1.1196	0.97969	3.2617	408.05	0.96001	7.72E-05	0.093962
286.62	4.9025	834.08	1.199E-03	229.61	235.49	1.121	0.9802	3.2756	406.59	0.96879	7.69E-05	0.093779
286.77	4.9199	832.88	1.201E-03	230.01	235.92	1.1224	0.98072	3.2897	405.12	0.97766	7.67E-05	0.093596
286.91	4.9373	831.67	1.202E-03	230.4	236.34	1.1238	0.98124	3.304	403.65	0.98663	7.64E-05	0.093413
287.06	4.9548	830.46	1.204E-03	230.8	236.77	1.1252	0.98176	3.3186	402.18	0.99571	7.62E-05	0.09323
287.2	4.9723	829.24	1.206E-03	231.2	237.19	1.1266	0.98229	3.3334	400.71	1.0049	7.60E-05	0.093047
287.35	4.9899	828.02	1.208E-03	231.59	237.62	1.1281	0.98283	3.3485	399.23	1.0142	7.57E-05	0.092864
287.5	5.0075	826.79	1.210E-03	231.99	238.05	1.1295	0.98337	3.3638	397.76	1.0236	7.55E-05	0.092681
287.64	5.0252	825.55	1.211E-03	232.39	238.48	1.1309	0.98392	3.3795	396.28	1.0331	7.53E-05	0.092498
287.79	5.043	824.31	1.213E-03	232.79	238.91	1.1323	0.98447	3.3953	394.79	1.0427	7.50E-05	0.092315

287.93	5.0607	823.07	1.215E-03	233.2	239.35	1.1338	0.98503	3.4115	393.31	1.0524	7.48E-05	0.092132
288.08	5.0786	821.81	1.217E-03	233.6	239.78	1.1352	0.98559	3.428	391.82	1.0623	7.45E-05	0.091949
288.23	5.0964	820.55	1.219E-03	234	240.22	1.1366	0.98617	3.4447	390.33	1.0722	7.43E-05	0.091767
288.37	5.1144	819.28	1.221E-03	234.41	240.65	1.1381	0.98675	3.4618	388.83	1.0823	7.41E-05	0.091584
288.52	5.1323	818.01	1.223E-03	234.82	241.09	1.1395	0.98733	3.4792	387.34	1.0925	7.38E-05	0.091401
288.66	5.1504	816.73	1.224E-03	235.23	241.53	1.141	0.98792	3.4969	385.84	1.1028	7.36E-05	0.091218
288.81	5.1684	815.44	1.226E-03	235.63	241.97	1.1424	0.98852	3.5149	384.34	1.1133	7.34E-05	0.091035
288.96	5.1865	814.15	1.228E-03	236.04	242.42	1.1439	0.98913	3.5332	382.83	1.1239	7.31E-05	0.090852
289.1	5.2047	812.85	1.230E-03	236.46	242.86	1.1453	0.98975	3.552	381.32	1.1346	7.29E-05	0.09067
289.25	5.2229	811.54	1.232E-03	236.87	243.31	1.1468	0.99037	3.571	379.81	1.1454	7.26E-05	0.090487
289.39	5.2412	810.22	1.234E-03	237.28	243.75	1.1483	0.991	3.5905	378.29	1.1564	7.24E-05	0.090305
289.54	5.2595	808.9	1.236E-03	237.7	244.2	1.1497	0.99164	3.6103	376.77	1.1675	7.22E-05	0.090122
289.68	5.2779	807.57	1.238E-03	238.12	244.65	1.1512	0.99229	3.6305	375.25	1.1788	7.19E-05	0.08994
289.83	5.2963	806.23	1.240E-03	238.53	245.1	1.1527	0.99295	3.6511	373.72	1.1902	7.17E-05	0.089758
289.98	5.3148	804.88	1.242E-03	238.95	245.56	1.1542	0.99362	3.6722	372.19	1.2018	7.14E-05	0.089576
290.12	5.3333	803.53	1.245E-03	239.37	246.01	1.1557	0.9943	3.6936	370.66	1.2135	7.12E-05	0.089394
290.27	5.3518	802.17	1.247E-03	239.8	246.47	1.1571	0.99499	3.7155	369.12	1.2254	7.10E-05	0.089212
290.41	5.3704	800.8	1.249E-03	240.22	246.93	1.1586	0.99569	3.7379	367.58	1.2374	7.07E-05	0.08903
290.56	5.3891	799.42	1.251E-03	240.64	247.39	1.1601	0.9964	3.7607	366.03	1.2496	7.05E-05	0.088849
290.71	5.4078	798.03	1.253E-03	241.07	247.85	1.1617	0.99712	3.784	364.48	1.262	7.02E-05	0.088668
290.85	5.4266	796.64	1.255E-03	241.5	248.31	1.1632	0.99785	3.8078	362.92	1.2745	7.00E-05	0.088487
291	5.4454	795.23	1.258E-03	241.93	248.78	1.1647	0.9986	3.8321	361.36	1.2872	6.98E-05	0.088306
291.14	5.4643	793.82	1.260E-03	242.36	249.24	1.1662	0.99936	3.857	359.79	1.3	6.95E-05	0.088125
291.29	5.4832	792.4	1.262E-03	242.79	249.71	1.1677	1.0001	3.8824	358.22	1.3131	6.93E-05	0.087945
291.44	5.5022	790.96	1.264E-03	243.23	250.18	1.1693	1.0009	3.9083	356.64	1.3263	6.90E-05	0.087765
291.58	5.5212	789.52	1.267E-03	243.66	250.66	1.1708	1.0017	3.9349	355.06	1.3398	6.88E-05	0.087586
291.73	5.5403	788.07	1.269E-03	244.1	251.13	1.1724	1.0025	3.962	353.47	1.3534	6.85E-05	0.087406
291.87	5.5594	786.61	1.271E-03	244.54	251.61	1.1739	1.0034	3.9898	351.88	1.3672	6.83E-05	0.087228
292.02	5.5786	785.14	1.274E-03	244.98	252.09	1.1755	1.0042	4.0182	350.28	1.3812	6.81E-05	0.087049
292.16	5.5978	783.66	1.276E-03	245.42	252.57	1.177	1.0051	4.0474	348.67	1.3954	6.78E-05	0.086871
292.31	5.6171	782.17	1.279E-03	245.87	253.05	1.1786	1.006	4.0772	347.06	1.4099	6.76E-05	0.086693
292.46	5.6364	780.67	1.281E-03	246.31	253.53	1.1802	1.0069	4.1077	345.44	1.4245	6.73E-05	0.086516
292.6	5.6558	779.16	1.283E-03	246.76	254.02	1.1817	1.0078	4.139	343.81	1.4394	6.71E-05	0.08634
292.75	5.6753	777.64	1.286E-03	247.21	254.51	1.1833	1.0087	4.1711	342.18	1.4545	6.68E-05	0.086164
292.89	5.6948	776.1	1.289E-03	247.66	255	1.1849	1.0097	4.204	340.54	1.4699	6.66E-05	0.085989
293.04	5.7143	774.56	1.291E-03	248.12	255.5	1.1865	1.0107	4.2377	338.89	1.4855	6.63E-05	0.085814
293.19	5.7339	773	1.294E-03	248.57	255.99	1.1881	1.0117	4.2723	337.24	1.5013	6.61E-05	0.08564
293.33	5.7536	771.43	1.296E-03	249.03	256.49	1.1897	1.0127	4.3079	335.57	1.5174	6.58E-05	0.085466
293.48	5.7733	769.85	1.299E-03	249.49	256.99	1.1914	1.0137	4.3444	333.9	1.5337	6.56E-05	0.085294
293.62	5.793	768.26	1.302E-03	249.95	257.5	1.193	1.0148	4.3818	332.22	1.5503	6.53E-05	0.085122
293.77	5.8129	766.65	1.304E-03	250.42	258	1.1946	1.0159	4.4204	330.53	1.5672	6.51E-05	0.084952

293.92	5.8327	765.03	1.307E-03	250.89	258.51	1.1963	1.0171	4.46	328.84	1.5844	6.48E-05	0.084782
294.06	5.8527	763.4	1.310E-03	251.35	259.02	1.1979	1.0182	4.5008	327.13	1.6019	6.46E-05	0.084613
294.21	5.8726	761.75	1.313E-03	251.83	259.54	1.1996	1.0194	4.5427	325.41	1.6196	6.43E-05	0.084445
294.35	5.8927	760.09	1.316E-03	252.3	260.05	1.2012	1.0206	4.5859	323.69	1.6377	6.41E-05	0.084279
294.5	5.9128	758.42	1.319E-03	252.78	260.57	1.2029	1.0219	4.6304	321.95	1.6561	6.38E-05	0.084114
294.65	5.9329	756.73	1.322E-03	253.25	261.09	1.2046	1.0232	4.6762	320.2	1.6748	6.36E-05	0.08395
294.79	5.9531	755.03	1.325E-03	253.74	261.62	1.2063	1.0245	4.7235	318.45	1.6939	6.33E-05	0.083788
294.94	5.9734	753.31	1.328E-03	254.22	262.15	1.208	1.0259	4.7723	316.68	1.7133	6.30E-05	0.083627
295.08	5.9937	751.57	1.331E-03	254.71	262.68	1.2097	1.0273	4.8227	314.9	1.7331	6.28E-05	0.083467
295.23	6.0141	749.82	1.334E-03	255.2	263.22	1.2114	1.0287	4.8747	313.11	1.7532	6.25E-05	0.08331
295.37	6.0345	748.05	1.337E-03	255.69	263.76	1.2132	1.0302	4.9285	311.31	1.7737	6.23E-05	0.083154
295.52	6.055	746.27	1.340E-03	256.18	264.3	1.2149	1.0317	4.9841	309.49	1.7946	6.20E-05	0.083001
295.67	6.0755	744.47	1.343E-03	256.68	264.84	1.2167	1.0333	5.0417	307.66	1.8159	6.17E-05	0.082849
295.81	6.0961	742.65	1.347E-03	257.18	265.39	1.2184	1.035	5.1013	305.82	1.8377	6.15E-05	0.0827
295.96	6.1168	740.81	1.350E-03	257.69	265.94	1.2202	1.0366	5.1631	303.97	1.8598	6.12E-05	0.082553
296.1	6.1375	738.95	1.353E-03	258.2	266.5	1.222	1.0384	5.2272	302.1	1.8825	6.09E-05	0.082409
296.25	6.1583	737.08	1.357E-03	258.71	267.06	1.2238	1.0402	5.2938	300.22	1.9055	6.07E-05	0.082268
296.4	6.1791	735.18	1.360E-03	259.22	267.63	1.2256	1.042	5.3628	298.32	1.9291	6.04E-05	0.082129
296.54	6.2	733.26	1.364E-03	259.74	268.19	1.2274	1.044	5.4347	296.41	1.9531	6.01E-05	0.081994
296.69	6.221	731.32	1.367E-03	260.26	268.77	1.2292	1.0459	5.5094	294.49	1.9777	5.99E-05	0.081862
296.83	6.242	729.36	1.371E-03	260.79	269.34	1.2311	1.048	5.5872	292.55	2.0028	5.96E-05	0.081734
296.98	6.263	727.37	1.375E-03	261.32	269.93	1.233	1.0501	5.6682	290.59	2.0284	5.93E-05	0.081609
297.13	6.2842	725.36	1.379E-03	261.85	270.51	1.2348	1.0523	5.7528	288.62	2.0546	5.90E-05	0.081489
297.27	6.3053	723.33	1.383E-03	262.39	271.11	1.2367	1.0546	5.841	286.63	2.0814	5.88E-05	0.081373
297.42	6.3266	721.27	1.386E-03	262.93	271.7	1.2386	1.057	5.9333	284.62	2.1088	5.85E-05	0.081262
297.56	6.3479	719.18	1.391E-03	263.48	272.3	1.2406	1.0595	6.0298	282.6	2.1368	5.82E-05	0.081156
297.71	6.3693	717.07	1.395E-03	264.03	272.91	1.2425	1.062	6.1308	280.55	2.1655	5.79E-05	0.081056
297.85	6.3907	714.93	1.399E-03	264.59	273.53	1.2445	1.0647	6.2367	278.49	2.1949	5.76E-05	0.080961
298	6.4122	712.76	1.403E-03	265.15	274.14	1.2464	1.0675	6.3478	276.41	2.225	5.73E-05	0.080872
298.15	6.4337	710.55	1.407E-03	265.72	274.77	1.2484	1.0703	6.4646	274.31	2.2558	5.71E-05	0.08079
298.29	6.4554	708.32	1.412E-03	266.29	275.4	1.2505	1.0733	6.5874	272.19	2.2873	5.68E-05	0.080716
298.44	6.477	706.05	1.416E-03	266.87	276.04	1.2525	1.0764	6.7167	270.05	2.3197	5.65E-05	0.080649
298.58	6.4988	703.75	1.421E-03	267.45	276.68	1.2545	1.0797	6.8531	267.89	2.3529	5.62E-05	0.08059
298.73	6.5206	701.41	1.426E-03	268.04	277.34	1.2566	1.0831	6.9971	265.71	2.3869	5.59E-05	0.08054
298.88	6.5424	699.03	1.431E-03	268.64	278	1.2587	1.0866	7.1494	263.5	2.4219	5.56E-05	0.080499
299.02	6.5644	696.62	1.436E-03	269.24	278.66	1.2609	1.0903	7.3107	261.28	2.4577	5.53E-05	0.080469
299.17	6.5864	694.16	1.441E-03	269.85	279.34	1.263	1.0942	7.4818	259.02	2.4946	5.49E-05	0.080449
299.31	6.6084	691.66	1.446E-03	270.47	280.03	1.2652	1.0982	7.6637	256.75	2.5324	5.46E-05	0.080442
299.46	6.6305	689.11	1.451E-03	271.1	280.72	1.2674	1.1024	7.8573	254.44	2.5714	5.43E-05	0.080447
299.61	6.6527	686.52	1.457E-03	271.73	281.42	1.2696	1.1068	8.0638	252.11	2.6114	5.40E-05	0.080465
299.75	6.675	683.87	1.462E-03	272.38	282.14	1.2719	1.1115	8.2846	249.75	2.6527	5.37E-05	0.080499

299.9	6.6973	681.17	1.468E-03	273.03	282.86	1.2742	1.1164	8.521	247.37	2.6951	5.33E-05	0.080548
300.04	6.7197	678.42	1.474E-03	273.69	283.6	1.2766	1.1215	8.775	244.95	2.7389	5.30E-05	0.080615
300.19	6.7422	675.6	1.480E-03	274.36	284.34	1.2789	1.1269	9.0483	242.5	2.7841	5.27E-05	0.0807
300.33	6.7647	672.73	1.487E-03	275.05	285.1	1.2814	1.1326	9.3435	240.01	2.8307	5.23E-05	0.080806
300.48	6.7873	669.78	1.493E-03	275.74	285.88	1.2838	1.1386	9.6631	237.49	2.8788	5.20E-05	0.080935
300.63	6.81	666.77	1.500E-03	276.45	286.66	1.2863	1.145	10.01	234.93	2.9286	5.16E-05	0.081088
300.77	6.8327	663.67	1.507E-03	277.17	287.47	1.2889	1.1517	10.389	232.33	2.9802	5.13E-05	0.081269
300.92	6.8555	660.5	1.514E-03	277.91	288.29	1.2915	1.1589	10.804	229.68	3.0336	5.09E-05	0.08148
301.06	6.8784	657.24	1.522E-03	278.66	289.12	1.2942	1.1665	11.26	226.98	3.0891	5.05E-05	0.081724
301.21	6.9013	653.88	1.529E-03	279.42	289.98	1.2969	1.1747	11.764	224.23	3.1467	5.01E-05	0.082006
301.36	6.9243	650.43	1.538E-03	280.21	290.85	1.2997	1.1835	12.324	221.41	3.2068	4.98E-05	0.082331
301.5	6.9474	646.86	1.546E-03	281.01	291.75	1.3025	1.1929	12.95	218.53	3.2694	4.94E-05	0.082704
301.65	6.9706	643.17	1.555E-03	281.84	292.68	1.3055	1.2031	13.655	215.58	3.3348	4.89E-05	0.083132
301.79	6.9938	639.34	1.564E-03	282.69	293.63	1.3085	1.2142	14.455	212.54	3.4033	4.85E-05	0.083625
301.94	7.0172	635.37	1.574E-03	283.56	294.6	1.3116	1.2262	15.369	209.41	3.4753	4.81E-05	0.084193
302.09	7.0405	631.24	1.584E-03	284.46	295.62	1.3149	1.2395	16.426	206.17	3.551	4.77E-05	0.084849
302.23	7.064	626.92	1.595E-03	285.4	296.66	1.3182	1.2542	17.661	202.81	3.6311	4.72E-05	0.085611
302.38	7.0876	622.39	1.607E-03	286.37	297.76	1.3217	1.2705	19.122	199.3	3.7159	4.67E-05	0.086504
302.52	7.1112	617.63	1.619E-03	287.38	298.89	1.3253	1.2889	20.877	195.64	3.8062	4.62E-05	0.087556
302.67	7.1349	612.58	1.632E-03	288.44	300.09	1.3291	1.3098	23.024	191.78	3.9028	4.57E-05	0.088811
302.82	7.1587	607.22	1.647E-03	289.56	301.35	1.3332	1.3338	25.706	187.7	4.0065	4.52E-05	0.090329
302.96	7.1826	601.47	1.663E-03	290.74	302.68	1.3375	1.3618	29.146	183.35	4.1187	4.46E-05	0.092195
303.11	7.2066	595.25	1.680E-03	292	304.11	1.342	1.3952	33.701	178.68	4.2408	4.40E-05	0.094543
303.25	7.2307	588.45	1.699E-03	293.37	305.66	1.347	1.4356	39.99	173.62	4.3746	4.33E-05	0.097585
303.4	7.2548	580.9	1.722E-03	294.87	307.36	1.3525	1.4861	49.167	168.06	4.5228	4.26E-05	0.10169
303.54	7.2791	572.34	1.747E-03	296.54	309.26	1.3586	1.5513	63.642	161.87	4.6887	4.18E-05	0.10754
303.69	7.3034	562.33	1.778E-03	298.47	311.46	1.3657	1.6402	89.318	154.83	4.8768	4.08E-05	0.11663
303.84	7.3279	550	1.818E-03	300.81	314.13	1.3744	1.7723	144.98	146.51	5.0943	3.97E-05	0.13297
303.98	7.3525	532.99	1.876E-03	303.99	317.79	1.3862	2.0083	331.98	135.77	5.3545	3.82E-05	0.17303
304.13	7.3773	467.6	2.139E-03	316.47	332.25	1.4336	undefined	undefined	undefined	5.8665	3.30E-05	undefined

Table 31. Saturated Vapor CO_2 Properties. Source: [18].

Temperature (K)	Pressure (MPa)	Density (v, kg/m3)	Volume (v, m3/kg)	Internal Energy (v, kJ/kg)	Enthalpy (v, kJ/kg)	Entropy (v, J/g*K)	Cv (v, J/g*K)	Cp (v, J/g*K)	Sound Spd. (v, m/s)	Joule-Thomson (v, K/MPa)	Viscosity (v, Pa*s)	Therm. Cond. (v, W/m*K)
216.59	0.51796	13.761	0.07267	392.78	430.42	2.139	0.6292	0.90872	222.78	26.174	1.10E-05	0.011014
216.74	0.52126	13.844	0.072231	392.82	430.47	2.1382	0.62961	0.90961	222.79	26.126	1.10E-05	0.011026
216.88	0.52457	13.928	0.071796	392.86	430.52	2.1373	0.63002	0.9105	222.81	26.078	1.10E-05	0.011038
217.03	0.52789	14.013	0.071364	392.91	430.58	2.1365	0.63043	0.91139	222.83	26.03	1.10E-05	0.01105
217.18	0.53124	14.097	0.070935	392.95	430.63	2.1356	0.63084	0.91229	222.85	25.982	1.10E-05	0.011062
217.32	0.53459	14.182	0.07051	392.99	430.69	2.1348	0.63125	0.91319	222.86	25.934	1.10E-05	0.011074
217.47	0.53797	14.268	0.070087	393.03	430.74	2.1339	0.63167	0.9141	222.88	25.887	1.10E-05	0.011086
217.61	0.54136	14.354	0.069668	393.08	430.79	2.1331	0.63208	0.91501	222.9	25.839	1.10E-05	0.011099
217.76	0.54476	14.44	0.069251	393.12	430.85	2.1322	0.63249	0.91592	222.92	25.792	1.10E-05	0.011111
217.91	0.54818	14.527	0.068838	393.16	430.9	2.1314	0.63291	0.91683	222.93	25.745	1.10E-05	0.011123
218.05	0.55162	14.614	0.068428	393.21	430.95	2.1306	0.63332	0.91775	222.95	25.698	1.10E-05	0.011135
218.2	0.55508	14.702	0.06802	393.25	431	2.1297	0.63374	0.91867	222.96	25.651	1.10E-05	0.011148
218.34	0.55855	14.789	0.067616	393.29	431.06	2.1289	0.63415	0.9196	222.98	25.604	1.10E-05	0.01116
218.49	0.56203	14.878	0.067214	393.33	431.11	2.128	0.63457	0.92052	223	25.558	1.11E-05	0.011172
218.63	0.56554	14.967	0.066816	393.37	431.16	2.1272	0.63499	0.92146	223.01	25.511	1.11E-05	0.011185
218.78	0.56906	15.056	0.06642	393.42	431.21	2.1264	0.63541	0.92239	223.03	25.465	1.11E-05	0.011197
218.93	0.57259	15.145	0.066027	393.46	431.26	2.1255	0.63583	0.92333	223.04	25.419	1.11E-05	0.011209
219.07	0.57615	15.235	0.065637	393.5	431.32	2.1247	0.63625	0.92427	223.06	25.373	1.11E-05	0.011222
219.22	0.57972	15.326	0.06525	393.54	431.37	2.1239	0.63667	0.92521	223.07	25.327	1.11E-05	0.011234
219.36	0.5833	15.417	0.064865	393.58	431.42	2.123	0.63709	0.92616	223.09	25.282	1.11E-05	0.011247
219.51	0.5869	15.508	0.064484	393.62	431.47	2.1222	0.63751	0.92711	223.1	25.236	1.11E-05	0.011259
219.66	0.59052	15.599	0.064105	393.66	431.52	2.1214	0.63794	0.92806	223.11	25.191	1.11E-05	0.011272
219.8	0.59416	15.692	0.063729	393.7	431.57	2.1206	0.63836	0.92902	223.13	25.145	1.11E-05	0.011284
219.95	0.59781	15.784	0.063355	393.75	431.62	2.1197	0.63879	0.92998	223.14	25.1	1.11E-05	0.011297
220.09	0.60148	15.877	0.062984	393.79	431.67	2.1189	0.63921	0.93094	223.16	25.055	1.11E-05	0.011309
220.24	0.60517	15.97	0.062616	393.83	431.72	2.1181	0.63964	0.93191	223.17	25.01	1.11E-05	0.011322
220.39	0.60887	16.064	0.06225	393.87	431.77	2.1173	0.64007	0.93288	223.18	24.966	1.12E-05	0.011334
220.53	0.61259	16.158	0.061887	393.91	431.82	2.1164	0.64049	0.93385	223.19	24.921	1.12E-05	0.011347
220.68	0.61633	16.253	0.061527	393.95	431.87	2.1156	0.64092	0.93483	223.21	24.877	1.12E-05	0.01136
220.82	0.62009	16.348	0.061169	393.99	431.92	2.1148	0.64135	0.93581	223.22	24.832	1.12E-05	0.011372
220.97	0.62386	16.444	0.060814	394.03	431.97	2.114	0.64178	0.9368	223.23	24.788	1.12E-05	0.011385
221.11	0.62765	16.54	0.060461	394.07	432.02	2.1132	0.64221	0.93779	223.24	24.744	1.12E-05	0.011398
221.26	0.63146	16.636	0.06011	394.11	432.06	2.1123	0.64265	0.93878	223.26	24.7	1.12E-05	0.01141
221.41	0.63528	16.733	0.059762	394.15	432.11	2.1115	0.64308	0.93977	223.27	24.656	1.12E-05	0.011423
221.55	0.63912	16.83	0.059417	394.19	432.16	2.1107	0.64351	0.94077	223.28	24.613	1.12E-05	0.011436
221.7	0.64298	16.928	0.059074	394.23	432.21	2.1099	0.64395	0.94177	223.29	24.569	1.12E-05	0.011449
221.84	0.64686	17.026	0.058733	394.26	432.26	2.1091	0.64438	0.94278	223.3	24.526	1.12E-05	0.011462
221.99	0.65075	17.125	0.058395	394.3	432.3	2.1083	0.64482	0.94379	223.31	24.482	1.12E-05	0.011474

222.14	0.65466	17.224	0.058059	394.34	432.35	2.1074	0.64525	0.9448	223.32	24.439	1.13E-05	0.011487
222.28	0.65859	17.323	0.057726	394.38	432.4	2.1066	0.64569	0.94582	223.33	24.396	1.13E-05	0.0115
222.43	0.66254	17.423	0.057395	394.42	432.45	2.1058	0.64613	0.94684	223.34	24.353	1.13E-05	0.011513
222.57	0.6665	17.524	0.057066	394.46	432.49	2.105	0.64657	0.94786	223.35	24.311	1.13E-05	0.011526
222.72	0.67049	17.625	0.056739	394.5	432.54	2.1042	0.64701	0.94889	223.36	24.268	1.13E-05	0.011539
222.87	0.67449	17.726	0.056415	394.53	432.59	2.1034	0.64745	0.94992	223.37	24.225	1.13E-05	0.011552
223.01	0.67851	17.828	0.056093	394.57	432.63	2.1026	0.64789	0.95096	223.38	24.183	1.13E-05	0.011565
223.16	0.68254	17.93	0.055773	394.61	432.68	2.1018	0.64833	0.952	223.39	24.141	1.13E-05	0.011578
223.3	0.6866	18.033	0.055455	394.65	432.72	2.101	0.64878	0.95304	223.4	24.099	1.13E-05	0.011591
223.45	0.69067	18.136	0.05514	394.69	432.77	2.1002	0.64922	0.95409	223.41	24.057	1.13E-05	0.011604
223.59	0.69476	18.239	0.054826	394.72	432.81	2.0994	0.64967	0.95514	223.42	24.015	1.13E-05	0.011618
223.74	0.69887	18.343	0.054515	394.76	432.86	2.0986	0.65011	0.95619	223.42	23.973	1.13E-05	0.011631
223.89	0.70299	18.448	0.054206	394.8	432.9	2.0978	0.65056	0.95725	223.43	23.931	1.13E-05	0.011644
224.03	0.70714	18.553	0.053899	394.84	432.95	2.097	0.65101	0.95831	223.44	23.89	1.14E-05	0.011657
224.18	0.7113	18.659	0.053595	394.87	432.99	2.0962	0.65145	0.95938	223.45	23.848	1.14E-05	0.01167
224.32	0.71548	18.765	0.053292	394.91	433.04	2.0954	0.6519	0.96045	223.46	23.807	1.14E-05	0.011684
224.47	0.71968	18.871	0.052991	394.95	433.08	2.0946	0.65235	0.96152	223.46	23.766	1.14E-05	0.011697
224.62	0.7239	18.978	0.052693	394.98	433.13	2.0938	0.6528	0.9626	223.47	23.725	1.14E-05	0.01171
224.76	0.72814	19.085	0.052396	395.02	433.17	2.093	0.65326	0.96368	223.48	23.684	1.14E-05	0.011723
224.91	0.73239	19.193	0.052102	395.06	433.21	2.0922	0.65371	0.96476	223.48	23.643	1.14E-05	0.011737
225.05	0.73666	19.301	0.051809	395.09	433.26	2.0914	0.65416	0.96585	223.49	23.602	1.14E-05	0.01175
225.2	0.74096	19.41	0.051519	395.13	433.3	2.0906	0.65461	0.96695	223.5	23.562	1.14E-05	0.011764
225.35	0.74527	19.52	0.05123	395.16	433.34	2.0898	0.65507	0.96805	223.5	23.521	1.14E-05	0.011777
225.49	0.7496	19.629	0.050944	395.2	433.39	2.089	0.65553	0.96915	223.51	23.481	1.14E-05	0.011791
225.64	0.75395	19.74	0.050659	395.23	433.43	2.0882	0.65598	0.97025	223.51	23.441	1.14E-05	0.011804
225.78	0.75831	19.851	0.050377	395.27	433.47	2.0874	0.65644	0.97136	223.52	23.401	1.15E-05	0.011818
225.93	0.7627	19.962	0.050096	395.31	433.51	2.0866	0.6569	0.97248	223.52	23.361	1.15E-05	0.011831
226.08	0.76711	20.074	0.049817	395.34	433.56	2.0859	0.65736	0.9736	223.53	23.321	1.15E-05	0.011845
226.22	0.77153	20.186	0.04954	395.38	433.6	2.0851	0.65782	0.97472	223.53	23.281	1.15E-05	0.011858
226.37	0.77597	20.299	0.049265	395.41	433.64	2.0843	0.65828	0.97584	223.54	23.241	1.15E-05	0.011872
226.51	0.78044	20.412	0.048991	395.45	433.68	2.0835	0.65874	0.97698	223.54	23.202	1.15E-05	0.011886
226.66	0.78492	20.526	0.04872	395.48	433.72	2.0827	0.6592	0.97811	223.54	23.162	1.15E-05	0.011899
226.8	0.78942	20.64	0.04845	395.51	433.76	2.0819	0.65967	0.97925	223.55	23.123	1.15E-05	0.011913
226.95	0.79394	20.755	0.048182	395.55	433.8	2.0811	0.66013	0.98039	223.55	23.084	1.15E-05	0.011927
227.1	0.79848	20.87	0.047916	395.58	433.84	2.0804	0.66059	0.98154	223.55	23.045	1.15E-05	0.011941
227.24	0.80304	20.986	0.047652	395.62	433.88	2.0796	0.66106	0.98269	223.56	23.006	1.15E-05	0.011954
227.39	0.80761	21.102	0.047389	395.65	433.92	2.0788	0.66153	0.98385	223.56	22.967	1.15E-05	0.011968
227.53	0.81221	21.219	0.047129	395.68	433.96	2.078	0.662	0.98501	223.56	22.928	1.16E-05	0.011982
227.68	0.81683	21.336	0.046869	395.72	434	2.0772	0.66246	0.98618	223.57	22.889	1.16E-05	0.011996
227.83	0.82146	21.454	0.046612	395.75	434.04	2.0765	0.66293	0.98735	223.57	22.851	1.16E-05	0.01201
227.97	0.82612	21.572	0.046356	395.78	434.08	2.0757	0.6634	0.98852	223.57	22.812	1.16E-05	0.012024

228.12	0.8308	21.691	0.046102	395.82	434.12	2.0749	0.66388	0.9897	223.57	22.774	1.16E-05	0.012038
228.26	0.83549	21.81	0.04585	395.85	434.16	2.0741	0.66435	0.99088	223.57	22.736	1.16E-05	0.012052
228.41	0.84021	21.93	0.0456	395.88	434.2	2.0734	0.66482	0.99207	223.57	22.697	1.16E-05	0.012066
228.56	0.84494	22.05	0.045351	395.92	434.24	2.0726	0.66529	0.99326	223.58	22.659	1.16E-05	0.01208
228.7	0.8497	22.171	0.045103	395.95	434.27	2.0718	0.66577	0.99446	223.58	22.621	1.16E-05	0.012094
228.85	0.85447	22.293	0.044858	395.98	434.31	2.071	0.66624	0.99566	223.58	22.584	1.16E-05	0.012108
228.99	0.85927	22.415	0.044613	396.01	434.35	2.0703	0.66672	0.99687	223.58	22.546	1.16E-05	0.012123
229.14	0.86408	22.537	0.044371	396.05	434.39	2.0695	0.6672	0.99808	223.58	22.508	1.16E-05	0.012137
229.28	0.86892	22.66	0.04413	396.08	434.42	2.0687	0.66768	0.99929	223.58	22.471	1.16E-05	0.012151
229.43	0.87377	22.784	0.043891	396.11	434.46	2.0679	0.66816	1.0005	223.58	22.433	1.17E-05	0.012165
229.58	0.87865	22.908	0.043653	396.14	434.5	2.0672	0.66864	1.0017	223.58	22.396	1.17E-05	0.01218
229.72	0.88354	23.033	0.043417	396.17	434.53	2.0664	0.66912	1.003	223.58	22.359	1.17E-05	0.012194
229.87	0.88846	23.158	0.043182	396.2	434.57	2.0656	0.6696	1.0042	223.58	22.322	1.17E-05	0.012208
230.01	0.89339	23.284	0.042949	396.24	434.61	2.0649	0.67008	1.0054	223.57	22.285	1.17E-05	0.012223
230.16	0.89835	23.41	0.042717	396.27	434.64	2.0641	0.67057	1.0067	223.57	22.248	1.17E-05	0.012237
230.31	0.90333	23.537	0.042487	396.3	434.68	2.0633	0.67105	1.0079	223.57	22.211	1.17E-05	0.012252
230.45	0.90832	23.664	0.042258	396.33	434.71	2.0626	0.67154	1.0092	223.57	22.174	1.17E-05	0.012266
230.6	0.91334	23.792	0.042031	396.36	434.75	2.0618	0.67202	1.0104	223.57	22.137	1.17E-05	0.012281
230.74	0.91838	23.92	0.041805	396.39	434.78	2.061	0.67251	1.0117	223.57	22.101	1.17E-05	0.012295
230.89	0.92344	24.049	0.041581	396.42	434.82	2.0603	0.673	1.013	223.56	22.065	1.17E-05	0.01231
231.04	0.92852	24.179	0.041358	396.45	434.85	2.0595	0.67349	1.0143	223.56	22.028	1.17E-05	0.012324
231.18	0.93362	24.309	0.041137	396.48	434.88	2.0587	0.67398	1.0155	223.56	21.992	1.18E-05	0.012339
231.33	0.93874	24.44	0.040917	396.51	434.92	2.058	0.67447	1.0168	223.55	21.956	1.18E-05	0.012354
231.47	0.94388	24.571	0.040698	396.54	434.95	2.0572	0.67496	1.0181	223.55	21.92	1.18E-05	0.012369
231.62	0.94904	24.703	0.040481	396.57	434.99	2.0565	0.67545	1.0194	223.55	21.884	1.18E-05	0.012383
231.76	0.95423	24.835	0.040265	396.6	435.02	2.0557	0.67595	1.0207	223.54	21.848	1.18E-05	0.012398
231.91	0.95943	24.968	0.040051	396.63	435.05	2.0549	0.67644	1.022	223.54	21.812	1.18E-05	0.012413
232.06	0.96466	25.102	0.039838	396.65	435.08	2.0542	0.67694	1.0233	223.54	21.777	1.18E-05	0.012428
232.2	0.96991	25.236	0.039626	396.68	435.12	2.0534	0.67743	1.0246	223.53	21.741	1.18E-05	0.012443
232.35	0.97517	25.371	0.039416	396.71	435.15	2.0527	0.67793	1.0259	223.53	21.706	1.18E-05	0.012458
232.49	0.98046	25.506	0.039207	396.74	435.18	2.0519	0.67843	1.0273	223.52	21.67	1.18E-05	0.012473
232.64	0.98577	25.642	0.038999	396.77	435.21	2.0512	0.67893	1.0286	223.52	21.635	1.18E-05	0.012488
232.79	0.99111	25.778	0.038793	396.8	435.24	2.0504	0.67943	1.0299	223.51	21.6	1.18E-05	0.012503
232.93	0.99646	25.915	0.038588	396.82	435.28	2.0496	0.67993	1.0313	223.5	21.565	1.19E-05	0.012518
233.08	1.0018	26.053	0.038384	396.85	435.31	2.0489	0.68043	1.0326	223.5	21.53	1.19E-05	0.012533
233.22	1.0072	26.191	0.038181	396.88	435.34	2.0481	0.68094	1.034	223.49	21.495	1.19E-05	0.012548
233.37	1.0126	26.33	0.03798	396.91	435.37	2.0474	0.68144	1.0353	223.49	21.46	1.19E-05	0.012563
233.52	1.0181	26.469	0.03778	396.93	435.4	2.0466	0.68194	1.0367	223.48	21.425	1.19E-05	0.012579
233.66	1.0235	26.609	0.037582	396.96	435.43	2.0459	0.68245	1.0381	223.47	21.391	1.19E-05	0.012594
233.81	1.029	26.749	0.037384	396.99	435.46	2.0451	0.68296	1.0394	223.47	21.356	1.19E-05	0.012609
233.95	1.0345	26.89	0.037188	397.02	435.49	2.0444	0.68346	1.0408	223.46	21.322	1.19E-05	0.012625

234.1	1.0401	27.032	0.036993	397.04	435.52	2.0436	0.68397	1.0422	223.45	21.287	1.19E-05	0.01264
234.25	1.0456	27.175	0.036799	397.07	435.55	2.0429	0.68448	1.0436	223.44	21.253	1.19E-05	0.012655
234.39	1.0512	27.317	0.036607	397.09	435.58	2.0421	0.68499	1.045	223.44	21.219	1.19E-05	0.012671
234.54	1.0568	27.461	0.036415	397.12	435.6	2.0414	0.6855	1.0464	223.43	21.185	1.19E-05	0.012686
234.68	1.0624	27.605	0.036225	397.15	435.63	2.0406	0.68602	1.0478	223.42	21.151	1.20E-05	0.012702
234.83	1.068	27.75	0.036036	397.17	435.66	2.0399	0.68653	1.0492	223.41	21.117	1.20E-05	0.012717
234.97	1.0737	27.895	0.035848	397.2	435.69	2.0391	0.68704	1.0506	223.4	21.083	1.20E-05	0.012733
235.12	1.0794	28.041	0.035662	397.22	435.72	2.0384	0.68756	1.052	223.39	21.049	1.20E-05	0.012749
235.27	1.0851	28.188	0.035476	397.25	435.74	2.0376	0.68808	1.0535	223.38	21.016	1.20E-05	0.012765
235.41	1.0908	28.335	0.035292	397.27	435.77	2.0369	0.68859	1.0549	223.37	20.982	1.20E-05	0.01278
235.56	1.0965	28.483	0.035109	397.3	435.8	2.0362	0.68911	1.0563	223.36	20.949	1.20E-05	0.012796
235.7	1.1023	28.631	0.034927	397.32	435.82	2.0354	0.68963	1.0578	223.35	20.915	1.20E-05	0.012812
235.85	1.1081	28.781	0.034746	397.35	435.85	2.0347	0.69015	1.0593	223.34	20.882	1.20E-05	0.012828
236	1.1139	28.93	0.034566	397.37	435.88	2.0339	0.69067	1.0607	223.33	20.849	1.20E-05	0.012844
236.14	1.1198	29.081	0.034387	397.4	435.9	2.0332	0.69119	1.0622	223.32	20.816	1.20E-05	0.01286
236.29	1.1256	29.232	0.034209	397.42	435.93	2.0324	0.69171	1.0636	223.31	20.783	1.21E-05	0.012876
236.43	1.1315	29.383	0.034033	397.44	435.95	2.0317	0.69224	1.0651	223.3	20.75	1.21E-05	0.012892
236.58	1.1374	29.536	0.033857	397.47	435.98	2.0309	0.69276	1.0666	223.29	20.717	1.21E-05	0.012908
236.73	1.1433	29.689	0.033683	397.49	436	2.0302	0.69329	1.0681	223.28	20.684	1.21E-05	0.012924
236.87	1.1493	29.842	0.03351	397.51	436.03	2.0295	0.69381	1.0696	223.27	20.651	1.21E-05	0.01294
237.02	1.1552	29.996	0.033337	397.54	436.05	2.0287	0.69434	1.0711	223.25	20.619	1.21E-05	0.012956
237.16	1.1612	30.151	0.033166	397.56	436.07	2.028	0.69487	1.0726	223.24	20.586	1.21E-05	0.012972
237.31	1.1673	30.307	0.032996	397.58	436.1	2.0272	0.6954	1.0741	223.23	20.554	1.21E-05	0.012989
237.45	1.1733	30.463	0.032827	397.61	436.12	2.0265	0.69593	1.0756	223.22	20.521	1.21E-05	0.013005
237.6	1.1794	30.62	0.032659	397.63	436.15	2.0258	0.69646	1.0772	223.2	20.489	1.21E-05	0.013021
237.75	1.1855	30.777	0.032492	397.65	436.17	2.025	0.69699	1.0787	223.19	20.457	1.21E-05	0.013038
237.89	1.1916	30.935	0.032326	397.67	436.19	2.0243	0.69753	1.0803	223.18	20.425	1.21E-05	0.013054
238.04	1.1977	31.094	0.03216	397.69	436.21	2.0236	0.69806	1.0818	223.16	20.392	1.22E-05	0.013071
238.18	1.2039	31.254	0.031996	397.72	436.23	2.0228	0.6986	1.0834	223.15	20.36	1.22E-05	0.013087
238.33	1.21	31.414	0.031833	397.74	436.26	2.0221	0.69913	1.0849	223.14	20.329	1.22E-05	0.013104
238.48	1.2163	31.575	0.031671	397.76	436.28	2.0213	0.69967	1.0865	223.12	20.297	1.22E-05	0.013121
238.62	1.2225	31.736	0.03151	397.78	436.3	2.0206	0.70021	1.0881	223.11	20.265	1.22E-05	0.013137
238.77	1.2287	31.898	0.03135	397.8	436.32	2.0199	0.70075	1.0896	223.09	20.233	1.22E-05	0.013154
238.91	1.235	32.061	0.031191	397.82	436.34	2.0191	0.70129	1.0912	223.08	20.202	1.22E-05	0.013171
239.06	1.2413	32.225	0.031032	397.84	436.36	2.0184	0.70183	1.0928	223.06	20.17	1.22E-05	0.013188
239.21	1.2476	32.389	0.030875	397.86	436.38	2.0177	0.70237	1.0944	223.05	20.139	1.22E-05	0.013205
239.35	1.254	32.554	0.030719	397.88	436.4	2.0169	0.70292	1.096	223.03	20.108	1.22E-05	0.013222
239.5	1.2604	32.719	0.030563	397.9	436.42	2.0162	0.70346	1.0977	223.01	20.076	1.22E-05	0.013239
239.64	1.2667	32.886	0.030409	397.92	436.44	2.0155	0.70401	1.0993	223	20.045	1.23E-05	0.013256
239.79	1.2732	33.053	0.030255	397.94	436.46	2.0147	0.70455	1.1009	222.98	20.014	1.23E-05	0.013273
239.93	1.2796	33.22	0.030102	397.96	436.48	2.014	0.7051	1.1026	222.97	19.983	1.23E-05	0.01329

240.08	1.2861	33.389	0.02995	397.98	436.5	2.0133	0.70565	1.1042	222.95	19.952	1.23E-05	0.013307
240.23	1.2926	33.558	0.029799	398	436.52	2.0125	0.7062	1.1059	222.93	19.921	1.23E-05	0.013324
240.37	1.2991	33.727	0.029649	398.02	436.53	2.0118	0.70675	1.1075	222.91	19.89	1.23E-05	0.013341
240.52	1.3056	33.898	0.0295	398.04	436.55	2.0111	0.7073	1.1092	222.9	19.86	1.23E-05	0.013359
240.66	1.3122	34.069	0.029352	398.05	436.57	2.0104	0.70785	1.1109	222.88	19.829	1.23E-05	0.013376
240.81	1.3188	34.241	0.029205	398.07	436.59	2.0096	0.70841	1.1125	222.86	19.798	1.23E-05	0.013394
240.96	1.3254	34.414	0.029058	398.09	436.6	2.0089	0.70896	1.1142	222.84	19.768	1.23E-05	0.013411
241.1	1.332	34.587	0.028913	398.11	436.62	2.0082	0.70952	1.1159	222.82	19.737	1.23E-05	0.013429
241.25	1.3387	34.761	0.028768	398.12	436.64	2.0074	0.71008	1.1176	222.8	19.707	1.23E-05	0.013446
241.39	1.3454	34.936	0.028624	398.14	436.65	2.0067	0.71063	1.1193	222.79	19.677	1.24E-05	0.013464
241.54	1.3521	35.111	0.028481	398.16	436.67	2.006	0.71119	1.1211	222.77	19.647	1.24E-05	0.013481
241.69	1.3588	35.288	0.028338	398.18	436.68	2.0052	0.71175	1.1228	222.75	19.617	1.24E-05	0.013499
241.83	1.3656	35.465	0.028197	398.19	436.7	2.0045	0.71232	1.1245	222.73	19.586	1.24E-05	0.013517
241.98	1.3723	35.642	0.028056	398.21	436.71	2.0038	0.71288	1.1263	222.71	19.556	1.24E-05	0.013535
242.12	1.3791	35.821	0.027917	398.23	436.73	2.0031	0.71344	1.128	222.69	19.527	1.24E-05	0.013553
242.27	1.386	36	0.027778	398.24	436.74	2.0023	0.71401	1.1298	222.67	19.497	1.24E-05	0.013571
242.42	1.3928	36.18	0.027639	398.26	436.75	2.0016	0.71458	1.1316	222.64	19.467	1.24E-05	0.013589
242.56	1.3997	36.361	0.027502	398.27	436.77	2.0009	0.71514	1.1333	222.62	19.437	1.24E-05	0.013607
242.71	1.4066	36.542	0.027366	398.29	436.78	2.0002	0.71571	1.1351	222.6	19.408	1.24E-05	0.013625
242.85	1.4136	36.725	0.02723	398.3	436.79	1.9994	0.71628	1.1369	222.58	19.378	1.24E-05	0.013643
243	1.4205	36.908	0.027095	398.32	436.81	1.9987	0.71685	1.1387	222.56	19.348	1.25E-05	0.013661
243.14	1.4275	37.091	0.02696	398.33	436.82	1.998	0.71743	1.1405	222.54	19.319	1.25E-05	0.01368
243.29	1.4345	37.276	0.026827	398.35	436.83	1.9973	0.718	1.1423	222.51	19.29	1.25E-05	0.013698
243.44	1.4415	37.461	0.026694	398.36	436.84	1.9965	0.71857	1.1442	222.49	19.26	1.25E-05	0.013716
243.58	1.4486	37.647	0.026562	398.38	436.86	1.9958	0.71915	1.146	222.47	19.231	1.25E-05	0.013735
243.73	1.4557	37.834	0.026431	398.39	436.87	1.9951	0.71973	1.1479	222.45	19.202	1.25E-05	0.013753
243.87	1.4628	38.022	0.026301	398.4	436.88	1.9944	0.72031	1.1497	222.42	19.173	1.25E-05	0.013772
244.02	1.4699	38.21	0.026171	398.42	436.89	1.9936	0.72089	1.1516	222.4	19.144	1.25E-05	0.01379
244.17	1.4771	38.399	0.026042	398.43	436.9	1.9929	0.72147	1.1535	222.38	19.115	1.25E-05	0.013809
244.31	1.4843	38.589	0.025914	398.44	436.91	1.9922	0.72205	1.1553	222.35	19.086	1.25E-05	0.013828
244.46	1.4915	38.78	0.025787	398.46	436.92	1.9915	0.72263	1.1572	222.33	19.057	1.25E-05	0.013847
244.6	1.4987	38.971	0.02566	398.47	436.93	1.9907	0.72322	1.1591	222.3	19.028	1.26E-05	0.013866
244.75	1.506	39.164	0.025534	398.48	436.94	1.99	0.72381	1.161	222.28	19	1.26E-05	0.013884
244.9	1.5133	39.357	0.025409	398.49	436.94	1.9893	0.72439	1.1629	222.25	18.971	1.26E-05	0.013903
245.04	1.5206	39.551	0.025284	398.51	436.95	1.9886	0.72498	1.1649	222.23	18.942	1.26E-05	0.013923
245.19	1.5279	39.745	0.02516	398.52	436.96	1.9878	0.72557	1.1668	222.2	18.914	1.26E-05	0.013942
245.33	1.5353	39.941	0.025037	398.53	436.97	1.9871	0.72617	1.1688	222.18	18.885	1.26E-05	0.013961
245.48	1.5427	40.137	0.024914	398.54	436.98	1.9864	0.72676	1.1707	222.15	18.857	1.26E-05	0.01398
245.62	1.5501	40.335	0.024793	398.55	436.98	1.9857	0.72735	1.1727	222.12	18.829	1.26E-05	0.013999
245.77	1.5576	40.533	0.024672	398.56	436.99	1.985	0.72795	1.1747	222.1	18.8	1.26E-05	0.014019
245.92	1.565	40.731	0.024551	398.57	437	1.9842	0.72855	1.1766	222.07	18.772	1.26E-05	0.014038

246.06	1.5725	40.931	0.024431	398.58	437	1.9835	0.72915	1.1786	222.04	18.744	1.26E-05	0.014058
246.21	1.5801	41.131	0.024312	398.59	437.01	1.9828	0.72975	1.1806	222.02	18.716	1.27E-05	0.014077
246.35	1.5876	41.333	0.024194	398.6	437.01	1.9821	0.73035	1.1827	221.99	18.688	1.27E-05	0.014097
246.5	1.5952	41.535	0.024076	398.61	437.02	1.9814	0.73095	1.1847	221.96	18.66	1.27E-05	0.014116
246.65	1.6028	41.738	0.023959	398.62	437.02	1.9806	0.73156	1.1867	221.93	18.632	1.27E-05	0.014136
246.79	1.6104	41.942	0.023843	398.63	437.03	1.9799	0.73217	1.1888	221.91	18.604	1.27E-05	0.014156
246.94	1.6181	42.146	0.023727	398.64	437.03	1.9792	0.73277	1.1908	221.88	18.576	1.27E-05	0.014176
247.08	1.6258	42.352	0.023612	398.65	437.04	1.9785	0.73338	1.1929	221.85	18.548	1.27E-05	0.014196
247.23	1.6335	42.558	0.023497	398.66	437.04	1.9778	0.73399	1.195	221.82	18.521	1.27E-05	0.014216
247.38	1.6412	42.765	0.023383	398.67	437.04	1.977	0.73461	1.1971	221.79	18.493	1.27E-05	0.014236
247.52	1.649	42.974	0.02327	398.67	437.05	1.9763	0.73522	1.1992	221.76	18.466	1.27E-05	0.014256
247.67	1.6568	43.183	0.023158	398.68	437.05	1.9756	0.73584	1.2013	221.73	18.438	1.27E-05	0.014276
247.81	1.6646	43.392	0.023046	398.69	437.05	1.9749	0.73646	1.2034	221.7	18.411	1.28E-05	0.014297
247.96	1.6724	43.603	0.022934	398.7	437.05	1.9742	0.73707	1.2055	221.67	18.383	1.28E-05	0.014317
248.11	1.6803	43.815	0.022823	398.7	437.05	1.9734	0.73769	1.2077	221.64	18.356	1.28E-05	0.014338
248.25	1.6882	44.027	0.022713	398.71	437.06	1.9727	0.73832	1.2098	221.61	18.328	1.28E-05	0.014358
248.4	1.6961	44.24	0.022604	398.72	437.06	1.972	0.73894	1.212	221.58	18.301	1.28E-05	0.014379
248.54	1.7041	44.455	0.022495	398.72	437.06	1.9713	0.73957	1.2142	221.55	18.274	1.28E-05	0.014399
248.69	1.7121	44.67	0.022387	398.73	437.06	1.9706	0.74019	1.2164	221.51	18.247	1.28E-05	0.01442
248.83	1.7201	44.886	0.022279	398.74	437.06	1.9698	0.74082	1.2186	221.48	18.22	1.28E-05	0.014441
248.98	1.7281	45.103	0.022172	398.74	437.06	1.9691	0.74145	1.2208	221.45	18.193	1.28E-05	0.014462
249.13	1.7362	45.32	0.022065	398.75	437.06	1.9684	0.74209	1.223	221.42	18.166	1.28E-05	0.014483
249.27	1.7443	45.539	0.021959	398.75	437.06	1.9677	0.74272	1.2252	221.38	18.139	1.29E-05	0.014504
249.42	1.7524	45.759	0.021854	398.76	437.05	1.967	0.74335	1.2275	221.35	18.112	1.29E-05	0.014525
249.56	1.7605	45.979	0.021749	398.76	437.05	1.9662	0.74399	1.2297	221.32	18.085	1.29E-05	0.014546
249.71	1.7687	46.201	0.021645	398.77	437.05	1.9655	0.74463	1.232	221.28	18.058	1.29E-05	0.014567
249.86	1.7769	46.423	0.021541	398.77	437.05	1.9648	0.74527	1.2343	221.25	18.031	1.29E-05	0.014589
250	1.7851	46.647	0.021438	398.77	437.04	1.9641	0.74591	1.2366	221.21	18.005	1.29E-05	0.01461
250.15	1.7934	46.871	0.021335	398.78	437.04	1.9634	0.74656	1.2389	221.18	17.978	1.29E-05	0.014632
250.29	1.8017	47.096	0.021233	398.78	437.04	1.9626	0.7472	1.2412	221.15	17.951	1.29E-05	0.014653
250.44	1.81	47.322	0.021132	398.78	437.03	1.9619	0.74785	1.2436	221.11	17.925	1.29E-05	0.014675
250.59	1.8183	47.549	0.021031	398.79	437.03	1.9612	0.7485	1.2459	221.08	17.898	1.29E-05	0.014697
250.73	1.8267	47.777	0.020931	398.79	437.02	1.9605	0.74915	1.2483	221.04	17.872	1.30E-05	0.014718
250.88	1.8351	48.006	0.020831	398.79	437.02	1.9598	0.7498	1.2506	221	17.846	1.30E-05	0.01474
251.02	1.8435	48.236	0.020731	398.79	437.01	1.959	0.75046	1.253	220.97	17.819	1.30E-05	0.014762
251.17	1.852	48.467	0.020633	398.8	437.01	1.9583	0.75112	1.2554	220.93	17.793	1.30E-05	0.014784
251.31	1.8605	48.699	0.020534	398.8	437	1.9576	0.75177	1.2578	220.89	17.767	1.30E-05	0.014807
251.46	1.869	48.932	0.020437	398.8	436.99	1.9569	0.75243	1.2603	220.86	17.74	1.30E-05	0.014829
251.61	1.8775	49.165	0.02034	398.8	436.99	1.9562	0.7531	1.2627	220.82	17.714	1.30E-05	0.014851
251.75	1.8861	49.4	0.020243	398.8	436.98	1.9554	0.75376	1.2651	220.78	17.688	1.30E-05	0.014874
251.9	1.8947	49.636	0.020147	398.8	436.97	1.9547	0.75442	1.2676	220.74	17.662	1.30E-05	0.014896

252.04	1.9033	49.873	0.020051	398.8	436.96	1.954	0.75509	1.2701	220.71	17.636	1.30E-05	0.014919
252.19	1.912	50.11	0.019956	398.8	436.96	1.9533	0.75576	1.2726	220.67	17.61	1.30E-05	0.014941
252.34	1.9206	50.349	0.019861	398.8	436.95	1.9526	0.75643	1.2751	220.63	17.584	1.31E-05	0.014964
252.48	1.9294	50.589	0.019767	398.8	436.94	1.9518	0.7571	1.2776	220.59	17.558	1.31E-05	0.014987
252.63	1.9381	50.829	0.019674	398.8	436.93	1.9511	0.75778	1.2801	220.55	17.532	1.31E-05	0.01501
252.77	1.9469	51.071	0.01958	398.8	436.92	1.9504	0.75845	1.2827	220.51	17.506	1.31E-05	0.015033
252.92	1.9557	51.314	0.019488	398.8	436.91	1.9497	0.75913	1.2853	220.47	17.481	1.31E-05	0.015056
253.07	1.9645	51.558	0.019396	398.79	436.9	1.949	0.75981	1.2878	220.43	17.455	1.31E-05	0.015079
253.21	1.9734	51.803	0.019304	398.79	436.89	1.9482	0.76049	1.2904	220.39	17.429	1.31E-05	0.015103
253.36	1.9822	52.048	0.019213	398.79	436.88	1.9475	0.76118	1.293	220.35	17.403	1.31E-05	0.015126
253.5	1.9912	52.295	0.019122	398.79	436.86	1.9468	0.76186	1.2957	220.31	17.378	1.31E-05	0.01515
253.65	2.0001	52.543	0.019032	398.79	436.85	1.9461	0.76255	1.2983	220.27	17.352	1.32E-05	0.015173
253.79	2.0091	52.792	0.018942	398.78	436.84	1.9454	0.76324	1.3009	220.23	17.327	1.32E-05	0.015197
253.94	2.0181	53.042	0.018853	398.78	436.83	1.9446	0.76393	1.3036	220.18	17.301	1.32E-05	0.015221
254.09	2.0271	53.293	0.018764	398.78	436.81	1.9439	0.76462	1.3063	220.14	17.276	1.32E-05	0.015245
254.23	2.0362	53.545	0.018676	398.77	436.8	1.9432	0.76532	1.309	220.1	17.25	1.32E-05	0.015268
254.38	2.0453	53.798	0.018588	398.77	436.78	1.9425	0.76602	1.3117	220.06	17.225	1.32E-05	0.015293
254.52	2.0544	54.052	0.018501	398.76	436.77	1.9417	0.76671	1.3144	220.01	17.2	1.32E-05	0.015317
254.67	2.0635	54.308	0.018414	398.76	436.75	1.941	0.76741	1.3172	219.97	17.174	1.32E-05	0.015341
254.82	2.0727	54.564	0.018327	398.75	436.74	1.9403	0.76812	1.3199	219.93	17.149	1.32E-05	0.015365
254.96	2.0819	54.822	0.018241	398.75	436.72	1.9396	0.76882	1.3227	219.88	17.124	1.32E-05	0.01539
255.11	2.0912	55.08	0.018155	398.74	436.71	1.9389	0.76953	1.3255	219.84	17.099	1.33E-05	0.015415
255.25	2.1004	55.34	0.01807	398.74	436.69	1.9381	0.77023	1.3283	219.79	17.074	1.33E-05	0.015439
255.4	2.1097	55.6	0.017985	398.73	436.67	1.9374	0.77094	1.3311	219.75	17.049	1.33E-05	0.015464
255.55	2.1191	55.862	0.017901	398.72	436.66	1.9367	0.77165	1.334	219.7	17.024	1.33E-05	0.015489
255.69	2.1284	56.125	0.017817	398.72	436.64	1.936	0.77237	1.3368	219.66	16.999	1.33E-05	0.015514
255.84	2.1378	56.389	0.017734	398.71	436.62	1.9352	0.77308	1.3397	219.61	16.974	1.33E-05	0.015539
255.98	2.1473	56.654	0.017651	398.7	436.6	1.9345	0.7738	1.3426	219.57	16.949	1.33E-05	0.015564
256.13	2.1567	56.921	0.017568	398.69	436.58	1.9338	0.77452	1.3455	219.52	16.924	1.33E-05	0.01559
256.28	2.1662	57.188	0.017486	398.68	436.56	1.9331	0.77524	1.3484	219.47	16.899	1.33E-05	0.015615
256.42	2.1757	57.457	0.017404	398.68	436.54	1.9323	0.77596	1.3514	219.43	16.874	1.33E-05	0.015641
256.57	2.1852	57.726	0.017323	398.67	436.52	1.9316	0.77669	1.3544	219.38	16.849	1.34E-05	0.015666
256.71	2.1948	57.997	0.017242	398.66	436.5	1.9309	0.77741	1.3573	219.33	16.825	1.34E-05	0.015692
256.86	2.2044	58.269	0.017162	398.65	436.48	1.9302	0.77814	1.3603	219.29	16.8	1.34E-05	0.015718
257	2.2141	58.542	0.017082	398.64	436.46	1.9294	0.77887	1.3633	219.24	16.775	1.34E-05	0.015744
257.15	2.2237	58.817	0.017002	398.63	436.44	1.9287	0.7796	1.3664	219.19	16.751	1.34E-05	0.01577
257.3	2.2334	59.092	0.016923	398.62	436.41	1.928	0.78034	1.3694	219.14	16.726	1.34E-05	0.015797
257.44	2.2432	59.369	0.016844	398.61	436.39	1.9273	0.78107	1.3725	219.09	16.701	1.34E-05	0.015823
257.59	2.2529	59.647	0.016765	398.6	436.37	1.9265	0.78181	1.3756	219.04	16.677	1.34E-05	0.015849
257.73	2.2627	59.926	0.016687	398.59	436.34	1.9258	0.78255	1.3787	218.99	16.652	1.34E-05	0.015876
257.88	2.2725	60.206	0.01661	398.57	436.32	1.9251	0.78329	1.3818	218.94	16.628	1.35E-05	0.015903

258.03	2.2824	60.488	0.016532	398.56	436.3	1.9243	0.78403	1.385	218.89	16.604	1.35E-05	0.01593
258.17	2.2923	60.77	0.016455	398.55	436.27	1.9236	0.78478	1.3881	218.84	16.579	1.35E-05	0.015957
258.32	2.3022	61.054	0.016379	398.54	436.24	1.9229	0.78552	1.3913	218.79	16.555	1.35E-05	0.015984
258.46	2.3121	61.339	0.016303	398.52	436.22	1.9222	0.78627	1.3945	218.74	16.531	1.35E-05	0.016011
258.61	2.3221	61.625	0.016227	398.51	436.19	1.9214	0.78702	1.3977	218.69	16.506	1.35E-05	0.016038
258.76	2.3321	61.913	0.016152	398.5	436.17	1.9207	0.78777	1.401	218.64	16.482	1.35E-05	0.016066
258.9	2.3421	62.202	0.016077	398.48	436.14	1.92	0.78853	1.4043	218.59	16.458	1.35E-05	0.016094
259.05	2.3522	62.492	0.016002	398.47	436.11	1.9192	0.78928	1.4075	218.53	16.434	1.35E-05	0.016121
259.19	2.3623	62.783	0.015928	398.46	436.08	1.9185	0.79004	1.4108	218.48	16.41	1.36E-05	0.016149
259.34	2.3725	63.075	0.015854	398.44	436.05	1.9178	0.7908	1.4142	218.43	16.386	1.36E-05	0.016177
259.48	2.3826	63.369	0.015781	398.43	436.02	1.917	0.79156	1.4175	218.38	16.361	1.36E-05	0.016205
259.63	2.3928	63.664	0.015707	398.41	435.99	1.9163	0.79232	1.4209	218.32	16.337	1.36E-05	0.016234
259.78	2.4031	63.961	0.015635	398.39	435.96	1.9156	0.79309	1.4243	218.27	16.313	1.36E-05	0.016262
259.92	2.4133	64.258	0.015562	398.38	435.93	1.9148	0.79386	1.4277	218.21	16.289	1.36E-05	0.016291
260.07	2.4236	64.557	0.01549	398.36	435.9	1.9141	0.79462	1.4311	218.16	16.266	1.36E-05	0.016319
260.21	2.4339	64.857	0.015418	398.34	435.87	1.9134	0.79539	1.4346	218.11	16.242	1.36E-05	0.016348
260.36	2.4443	65.159	0.015347	398.33	435.84	1.9126	0.79617	1.438	218.05	16.218	1.36E-05	0.016377
260.51	2.4547	65.462	0.015276	398.31	435.81	1.9119	0.79694	1.4415	218	16.194	1.37E-05	0.016406
260.65	2.4651	65.766	0.015205	398.29	435.77	1.9112	0.79772	1.4451	217.94	16.17	1.37E-05	0.016436
260.8	2.4756	66.071	0.015135	398.27	435.74	1.9104	0.79849	1.4486	217.88	16.146	1.37E-05	0.016465
260.94	2.4861	66.378	0.015065	398.25	435.71	1.9097	0.79927	1.4522	217.83	16.123	1.37E-05	0.016495
261.09	2.4966	66.686	0.014996	398.24	435.67	1.909	0.80006	1.4558	217.77	16.099	1.37E-05	0.016524
261.24	2.5071	66.996	0.014926	398.22	435.64	1.9082	0.80084	1.4594	217.72	16.075	1.37E-05	0.016554
261.38	2.5177	67.306	0.014857	398.2	435.6	1.9075	0.80162	1.463	217.66	16.052	1.37E-05	0.016584
261.53	2.5283	67.619	0.014789	398.18	435.57	1.9067	0.80241	1.4667	217.6	16.028	1.37E-05	0.016614
261.67	2.539	67.932	0.014721	398.16	435.53	1.906	0.8032	1.4703	217.54	16.005	1.37E-05	0.016645
261.82	2.5497	68.247	0.014653	398.13	435.49	1.9053	0.80399	1.4741	217.49	15.981	1.38E-05	0.016675
261.96	2.5604	68.563	0.014585	398.11	435.46	1.9045	0.80478	1.4778	217.43	15.958	1.38E-05	0.016706
262.11	2.5711	68.881	0.014518	398.09	435.42	1.9038	0.80558	1.4815	217.37	15.934	1.38E-05	0.016736
262.26	2.5819	69.2	0.014451	398.07	435.38	1.903	0.80638	1.4853	217.31	15.911	1.38E-05	0.016767
262.4	2.5927	69.521	0.014384	398.05	435.34	1.9023	0.80717	1.4891	217.25	15.887	1.38E-05	0.016799
262.55	2.6036	69.843	0.014318	398.02	435.3	1.9015	0.80797	1.493	217.19	15.864	1.38E-05	0.01683
262.69	2.6145	70.166	0.014252	398	435.26	1.9008	0.80878	1.4968	217.13	15.841	1.38E-05	0.016861
262.84	2.6254	70.491	0.014186	397.98	435.22	1.9001	0.80958	1.5007	217.07	15.817	1.38E-05	0.016893
262.99	2.6363	70.817	0.014121	397.95	435.18	1.8993	0.81039	1.5046	217.01	15.794	1.39E-05	0.016925
263.13	2.6473	71.144	0.014056	397.93	435.14	1.8986	0.8112	1.5086	216.95	15.771	1.39E-05	0.016957
263.28	2.6583	71.474	0.013991	397.91	435.1	1.8978	0.81201	1.5125	216.89	15.748	1.39E-05	0.016989
263.42	2.6694	71.804	0.013927	397.88	435.06	1.8971	0.81282	1.5165	216.83	15.724	1.39E-05	0.017021
263.57	2.6805	72.136	0.013863	397.85	435.01	1.8963	0.81363	1.5205	216.77	15.701	1.39E-05	0.017053
263.72	2.6916	72.47	0.013799	397.83	434.97	1.8956	0.81445	1.5246	216.71	15.678	1.39E-05	0.017086
263.86	2.7027	72.805	0.013735	397.8	434.93	1.8948	0.81527	1.5287	216.64	15.655	1.39E-05	0.017119

264.01	2.7139	73.141	0.013672	397.78	434.88	1.8941	0.81609	1.5328	216.58	15.632	1.39E-05	0.017152
264.15	2.7251	73.479	0.013609	397.75	434.84	1.8933	0.81691	1.5369	216.52	15.609	1.39E-05	0.017185
264.3	2.7364	73.819	0.013547	397.72	434.79	1.8926	0.81773	1.5411	216.46	15.586	1.40E-05	0.017218
264.45	2.7477	74.16	0.013484	397.69	434.74	1.8918	0.81856	1.5453	216.39	15.563	1.40E-05	0.017252
264.59	2.759	74.502	0.013422	397.67	434.7	1.8911	0.81939	1.5495	216.33	15.54	1.40E-05	0.017286
264.74	2.7704	74.846	0.013361	397.64	434.65	1.8903	0.82022	1.5537	216.27	15.517	1.40E-05	0.017319
264.88	2.7817	75.192	0.013299	397.61	434.6	1.8896	0.82105	1.558	216.2	15.494	1.40E-05	0.017354
265.03	2.7932	75.539	0.013238	397.58	434.55	1.8888	0.82188	1.5623	216.14	15.471	1.40E-05	0.017388
265.17	2.8046	75.888	0.013177	397.55	434.51	1.8881	0.82272	1.5667	216.07	15.448	1.40E-05	0.017422
265.32	2.8161	76.238	0.013117	397.52	434.46	1.8873	0.82356	1.5711	216.01	15.425	1.40E-05	0.017457
265.47	2.8276	76.59	0.013056	397.49	434.41	1.8866	0.8244	1.5755	215.94	15.402	1.41E-05	0.017492
265.61	2.8392	76.944	0.012996	397.46	434.36	1.8858	0.82524	1.5799	215.88	15.38	1.41E-05	0.017527
265.76	2.8508	77.299	0.012937	397.43	434.31	1.885	0.82609	1.5844	215.81	15.357	1.41E-05	0.017562
265.9	2.8624	77.656	0.012877	397.39	434.25	1.8843	0.82693	1.5889	215.74	15.334	1.41E-05	0.017598
266.05	2.8741	78.014	0.012818	397.36	434.2	1.8835	0.82778	1.5934	215.68	15.311	1.41E-05	0.017633
266.2	2.8858	78.374	0.012759	397.33	434.15	1.8828	0.82863	1.598	215.61	15.289	1.41E-05	0.017669
266.34	2.8975	78.736	0.012701	397.29	434.09	1.882	0.82949	1.6026	215.54	15.266	1.41E-05	0.017705
266.49	2.9093	79.099	0.012642	397.26	434.04	1.8812	0.83034	1.6073	215.48	15.243	1.41E-05	0.017742
266.63	2.9211	79.464	0.012584	397.23	433.99	1.8805	0.8312	1.6119	215.41	15.221	1.42E-05	0.017778
266.78	2.9329	79.831	0.012527	397.19	433.93	1.8797	0.83206	1.6167	215.34	15.198	1.42E-05	0.017815
266.93	2.9448	80.199	0.012469	397.16	433.88	1.8789	0.83293	1.6214	215.27	15.176	1.42E-05	0.017852
267.07	2.9567	80.569	0.012412	397.12	433.82	1.8782	0.83379	1.6262	215.2	15.153	1.42E-05	0.017889
267.22	2.9687	80.941	0.012355	397.09	433.76	1.8774	0.83466	1.631	215.13	15.131	1.42E-05	0.017927
267.36	2.9806	81.314	0.012298	397.05	433.7	1.8766	0.83553	1.6359	215.06	15.108	1.42E-05	0.017964
267.51	2.9927	81.689	0.012241	397.01	433.65	1.8759	0.8364	1.6408	214.99	15.086	1.42E-05	0.018002
267.65	3.0047	82.066	0.012185	396.97	433.59	1.8751	0.83728	1.6457	214.92	15.063	1.43E-05	0.01804
267.8	3.0168	82.445	0.012129	396.94	433.53	1.8743	0.83815	1.6507	214.85	15.041	1.43E-05	0.018079
267.95	3.0289	82.826	0.012074	396.9	433.47	1.8736	0.83903	1.6557	214.78	15.018	1.43E-05	0.018117
268.09	3.0411	83.208	0.012018	396.86	433.41	1.8728	0.83991	1.6607	214.71	14.996	1.43E-05	0.018156
268.24	3.0533	83.592	0.011963	396.82	433.35	1.872	0.8408	1.6658	214.64	14.973	1.43E-05	0.018195
268.38	3.0655	83.978	0.011908	396.78	433.28	1.8712	0.84168	1.671	214.57	14.951	1.43E-05	0.018234
268.53	3.0778	84.365	0.011853	396.74	433.22	1.8705	0.84257	1.6762	214.5	14.929	1.43E-05	0.018274
268.68	3.0901	84.755	0.011799	396.7	433.16	1.8697	0.84347	1.6814	214.42	14.906	1.43E-05	0.018314
268.82	3.1024	85.146	0.011745	396.66	433.1	1.8689	0.84436	1.6866	214.35	14.884	1.44E-05	0.018354
268.97	3.1148	85.539	0.011691	396.62	433.03	1.8681	0.84526	1.6919	214.28	14.862	1.44E-05	0.018394
269.11	3.1272	85.934	0.011637	396.58	432.97	1.8674	0.84616	1.6973	214.2	14.839	1.44E-05	0.018435
269.26	3.1396	86.331	0.011583	396.53	432.9	1.8666	0.84706	1.7027	214.13	14.817	1.44E-05	0.018475
269.41	3.1521	86.729	0.01153	396.49	432.83	1.8658	0.84796	1.7081	214.06	14.795	1.44E-05	0.018516
269.55	3.1646	87.13	0.011477	396.45	432.77	1.865	0.84887	1.7136	213.98	14.772	1.44E-05	0.018558
269.7	3.1772	87.532	0.011424	396.4	432.7	1.8642	0.84978	1.7191	213.91	14.75	1.44E-05	0.018599
269.84	3.1898	87.937	0.011372	396.36	432.63	1.8634	0.8507	1.7247	213.83	14.728	1.45E-05	0.018641

269.99	3.2024	88.343	0.01132	396.31	432.56	1.8627	0.85161	1.7303	213.76	14.706	1.45E-05	0.018684
270.13	3.2151	88.751	0.011267	396.27	432.49	1.8619	0.85253	1.7359	213.68	14.684	1.45E-05	0.018726
270.28	3.2278	89.162	0.011216	396.22	432.42	1.8611	0.85345	1.7417	213.61	14.661	1.45E-05	0.018769
270.43	3.2405	89.574	0.011164	396.17	432.35	1.8603	0.85438	1.7474	213.53	14.639	1.45E-05	0.018812
270.57	3.2533	89.988	0.011113	396.13	432.28	1.8595	0.8553	1.7532	213.45	14.617	1.45E-05	0.018855
270.72	3.2661	90.404	0.011061	396.08	432.21	1.8587	0.85624	1.7591	213.38	14.595	1.45E-05	0.018899
270.86	3.2789	90.822	0.011011	396.03	432.13	1.8579	0.85717	1.765	213.3	14.573	1.46E-05	0.018942
271.01	3.2918	91.243	0.01096	395.98	432.06	1.8571	0.8581	1.771	213.22	14.551	1.46E-05	0.018987
271.16	3.3048	91.665	0.010909	395.93	431.98	1.8563	0.85904	1.777	213.14	14.528	1.46E-05	0.019031
271.3	3.3177	92.089	0.010859	395.88	431.91	1.8555	0.85999	1.783	213.06	14.506	1.46E-05	0.019076
271.45	3.3307	92.515	0.010809	395.83	431.83	1.8547	0.86093	1.7892	212.99	14.484	1.46E-05	0.019121
271.59	3.3437	92.944	0.010759	395.78	431.76	1.8539	0.86188	1.7953	212.91	14.462	1.46E-05	0.019166
271.74	3.3568	93.374	0.01071	395.73	431.68	1.8531	0.86283	1.8016	212.83	14.44	1.46E-05	0.019212
271.89	3.3699	93.807	0.01066	395.68	431.6	1.8523	0.86379	1.8078	212.75	14.418	1.47E-05	0.019258
272.03	3.3831	94.242	0.010611	395.62	431.52	1.8515	0.86475	1.8142	212.67	14.396	1.47E-05	0.019305
272.18	3.3963	94.679	0.010562	395.57	431.44	1.8507	0.86571	1.8206	212.59	14.374	1.47E-05	0.019351
272.32	3.4095	95.118	0.010513	395.52	431.36	1.8499	0.86667	1.827	212.51	14.352	1.47E-05	0.019398
272.47	3.4228	95.559	0.010465	395.46	431.28	1.8491	0.86764	1.8335	212.42	14.33	1.47E-05	0.019446
272.62	3.4361	96.003	0.010416	395.41	431.2	1.8483	0.86861	1.8401	212.34	14.308	1.47E-05	0.019493
272.76	3.4494	96.448	0.010368	395.35	431.12	1.8475	0.86959	1.8468	212.26	14.286	1.47E-05	0.019541
272.91	3.4628	96.896	0.01032	395.3	431.03	1.8467	0.87056	1.8535	212.18	14.264	1.48E-05	0.01959
273.05	3.4762	97.346	0.010273	395.24	430.95	1.8458	0.87155	1.8602	212.1	14.242	1.48E-05	0.019639
273.2	3.4896	97.799	0.010225	395.18	430.86	1.845	0.87253	1.867	212.01	14.219	1.48E-05	0.019688
273.34	3.5031	98.253	0.010178	395.13	430.78	1.8442	0.87352	1.8739	211.93	14.197	1.48E-05	0.019737
273.49	3.5167	98.71	0.010131	395.07	430.69	1.8434	0.87451	1.8809	211.85	14.175	1.48E-05	0.019787
273.64	3.5302	99.17	0.010084	395.01	430.61	1.8426	0.87551	1.8879	211.76	14.153	1.48E-05	0.019837
273.78	3.5438	99.631	0.010037	394.95	430.52	1.8417	0.87651	1.895	211.68	14.131	1.49E-05	0.019888
273.93	3.5575	100.1	0.0099905	394.89	430.43	1.8409	0.87751	1.9021	211.59	14.109	1.49E-05	0.019939
274.07	3.5712	100.56	0.0099442	394.83	430.34	1.8401	0.87852	1.9094	211.51	14.087	1.49E-05	0.01999
274.22	3.5849	101.03	0.0098981	394.77	430.25	1.8393	0.87953	1.9167	211.42	14.065	1.49E-05	0.020042
274.37	3.5987	101.5	0.0098521	394.7	430.16	1.8384	0.88054	1.924	211.34	14.043	1.49E-05	0.020094
274.51	3.6125	101.97	0.0098064	394.64	430.07	1.8376	0.88156	1.9315	211.25	14.021	1.49E-05	0.020146
274.66	3.6263	102.45	0.0097608	394.58	429.97	1.8368	0.88258	1.939	211.16	13.999	1.49E-05	0.020199
274.8	3.6402	102.93	0.0097155	394.51	429.88	1.836	0.88361	1.9466	211.08	13.977	1.50E-05	0.020253
274.95	3.6541	103.41	0.0096703	394.45	429.78	1.8351	0.88464	1.9542	210.99	13.955	1.50E-05	0.020306
275.1	3.668	103.89	0.0096253	394.38	429.69	1.8343	0.88568	1.962	210.9	13.933	1.50E-05	0.02036
275.24	3.682	104.38	0.0095805	394.32	429.59	1.8334	0.88671	1.9698	210.81	13.911	1.50E-05	0.020415
275.39	3.6961	104.87	0.0095359	394.25	429.5	1.8326	0.88776	1.9777	210.72	13.889	1.50E-05	0.02047
275.53	3.7102	105.36	0.0094915	394.18	429.4	1.8318	0.8888	1.9857	210.64	13.867	1.50E-05	0.020525
275.68	3.7243	105.85	0.0094472	394.11	429.3	1.8309	0.88986	1.9937	210.55	13.845	1.51E-05	0.020581
275.82	3.7384	106.35	0.0094032	394.05	429.2	1.8301	0.89091	2.0019	210.46	13.823	1.51E-05	0.020638

275.97	3.7526	106.85	0.0093593	393.98	429.1	1.8292	0.89197	2.0101	210.37	13.801	1.51E-05	0.020694
276.12	3.7669	107.35	0.0093156	393.91	429	1.8284	0.89303	2.0184	210.28	13.779	1.51E-05	0.020752
276.26	3.7811	107.85	0.009272	393.84	428.89	1.8275	0.8941	2.0268	210.19	13.756	1.51E-05	0.020809
276.41	3.7955	108.36	0.0092287	393.76	428.79	1.8267	0.89518	2.0353	210.09	13.734	1.51E-05	0.020868
276.55	3.8098	108.87	0.0091855	393.69	428.69	1.8258	0.89625	2.0439	210	13.712	1.52E-05	0.020926
276.7	3.8242	109.38	0.0091425	393.62	428.58	1.825	0.89734	2.0525	209.91	13.69	1.52E-05	0.020985
276.85	3.8386	109.89	0.0090997	393.54	428.48	1.8241	0.89842	2.0613	209.82	13.668	1.52E-05	0.021045
276.99	3.8531	110.41	0.009057	393.47	428.37	1.8232	0.89951	2.0702	209.73	13.646	1.52E-05	0.021105
277.14	3.8676	110.93	0.0090145	393.4	428.26	1.8224	0.90061	2.0791	209.63	13.624	1.52E-05	0.021166
277.28	3.8822	111.46	0.0089722	393.32	428.15	1.8215	0.90171	2.0882	209.54	13.601	1.53E-05	0.021227
277.43	3.8968	111.98	0.0089301	393.24	428.04	1.8206	0.90282	2.0973	209.44	13.579	1.53E-05	0.021289
277.58	3.9114	112.51	0.0088881	393.17	427.93	1.8198	0.90393	2.1066	209.35	13.557	1.53E-05	0.021351
277.72	3.9261	113.04	0.0088463	393.09	427.82	1.8189	0.90504	2.1159	209.26	13.535	1.53E-05	0.021413
277.87	3.9408	113.58	0.0088046	393.01	427.71	1.818	0.90616	2.1254	209.16	13.512	1.53E-05	0.021477
278.01	3.9556	114.11	0.0087631	392.93	427.59	1.8172	0.90729	2.135	209.06	13.49	1.53E-05	0.02154
278.16	3.9704	114.65	0.0087218	392.85	427.48	1.8163	0.90842	2.1446	208.97	13.468	1.54E-05	0.021605
278.31	3.9852	115.2	0.0086807	392.77	427.36	1.8154	0.90956	2.1544	208.87	13.446	1.54E-05	0.02167
278.45	4.0001	115.75	0.0086397	392.69	427.24	1.8145	0.9107	2.1643	208.77	13.423	1.54E-05	0.021735
278.6	4.015	116.29	0.0085988	392.6	427.13	1.8136	0.91185	2.1743	208.68	13.401	1.54E-05	0.021801
278.74	4.03	116.85	0.0085582	392.52	427.01	1.8127	0.913	2.1845	208.58	13.379	1.54E-05	0.021868
278.89	4.045	117.4	0.0085176	392.43	426.89	1.8118	0.91416	2.1947	208.48	13.356	1.55E-05	0.021935
279.03	4.0601	117.96	0.0084773	392.35	426.77	1.811	0.91532	2.2051	208.38	13.334	1.55E-05	0.022003
279.18	4.0752	118.52	0.0084371	392.26	426.65	1.8101	0.91649	2.2156	208.28	13.311	1.55E-05	0.022071
279.33	4.0903	119.09	0.008397	392.18	426.52	1.8092	0.91766	2.2262	208.18	13.289	1.55E-05	0.02214
279.47	4.1055	119.66	0.0083571	392.09	426.4	1.8083	0.91884	2.2369	208.08	13.266	1.55E-05	0.02221
279.62	4.1207	120.23	0.0083174	392	426.27	1.8074	0.92003	2.2478	207.98	13.244	1.56E-05	0.02228
279.76	4.136	120.81	0.0082778	391.91	426.15	1.8065	0.92122	2.2588	207.88	13.221	1.56E-05	0.022351
279.91	4.1513	121.38	0.0082383	391.82	426.02	1.8056	0.92242	2.2699	207.78	13.199	1.56E-05	0.022423
280.06	4.1666	121.97	0.008199	391.73	425.89	1.8046	0.92362	2.2812	207.68	13.176	1.56E-05	0.022495
280.2	4.182	122.55	0.0081599	391.64	425.76	1.8037	0.92483	2.2926	207.58	13.154	1.56E-05	0.022568
280.35	4.1974	123.14	0.0081209	391.54	425.63	1.8028	0.92605	2.3042	207.47	13.131	1.56E-05	0.022642
280.49	4.2129	123.73	0.008082	391.45	425.5	1.8019	0.92727	2.3159	207.37	13.108	1.57E-05	0.022716
280.64	4.2284	124.33	0.0080433	391.36	425.37	1.801	0.9285	2.3277	207.27	13.086	1.57E-05	0.022791
280.79	4.244	124.93	0.0080047	391.26	425.23	1.8001	0.92974	2.3397	207.16	13.063	1.57E-05	0.022867
280.93	4.2596	125.53	0.0079663	391.16	425.1	1.7991	0.93098	2.3518	207.06	13.04	1.57E-05	0.022944
281.08	4.2752	126.13	0.007928	391.07	424.96	1.7982	0.93223	2.3641	206.95	13.017	1.58E-05	0.023021
281.22	4.2909	126.74	0.0078899	390.97	424.82	1.7973	0.93348	2.3766	206.85	12.994	1.58E-05	0.023099
281.37	4.3066	127.36	0.0078519	390.87	424.68	1.7963	0.93475	2.3892	206.74	12.972	1.58E-05	0.023178
281.51	4.3224	127.97	0.007814	390.77	424.54	1.7954	0.93601	2.402	206.64	12.949	1.58E-05	0.023257
281.66	4.3382	128.6	0.0077763	390.67	424.4	1.7945	0.93729	2.415	206.53	12.926	1.58E-05	0.023338
281.81	4.3541	129.22	0.0077387	390.56	424.26	1.7935	0.93857	2.4281	206.42	12.903	1.59E-05	0.023419

281.95	4.37	129.85	0.0077013	390.46	424.11	1.7926	0.93986	2.4414	206.31	12.88	1.59E-05	0.023501
282.1	4.3859	130.48	0.007664	390.36	423.97	1.7916	0.94116	2.4549	206.2	12.857	1.59E-05	0.023583
282.24	4.4019	131.12	0.0076268	390.25	423.82	1.7907	0.94247	2.4686	206.1	12.833	1.59E-05	0.023667
282.39	4.418	131.76	0.0075897	390.14	423.68	1.7897	0.94378	2.4824	205.99	12.81	1.59E-05	0.023752
282.54	4.434	132.4	0.0075528	390.04	423.53	1.7888	0.9451	2.4965	205.88	12.787	1.60E-05	0.023837
282.68	4.4502	133.05	0.007516	389.93	423.38	1.7878	0.94643	2.5107	205.77	12.764	1.60E-05	0.023923
282.83	4.4663	133.7	0.0074794	389.82	423.22	1.7868	0.94776	2.5252	205.65	12.74	1.60E-05	0.02401
282.97	4.4825	134.36	0.0074428	389.71	423.07	1.7859	0.9491	2.5398	205.54	12.717	1.60E-05	0.024098
283.12	4.4988	135.02	0.0074064	389.6	422.92	1.7849	0.95045	2.5547	205.43	12.694	1.61E-05	0.024187
283.27	4.5151	135.68	0.0073701	389.48	422.76	1.7839	0.95181	2.5697	205.32	12.67	1.61E-05	0.024277
283.41	4.5314	136.35	0.007334	389.37	422.6	1.7829	0.95318	2.585	205.2	12.647	1.61E-05	0.024368
283.56	4.5478	137.02	0.007298	389.26	422.44	1.782	0.95456	2.6005	205.09	12.623	1.61E-05	0.02446
283.7	4.5642	137.7	0.0072621	389.14	422.28	1.781	0.95594	2.6162	204.98	12.6	1.61E-05	0.024553
283.85	4.5807	138.38	0.0072263	389.02	422.12	1.78	0.95733	2.6322	204.86	12.576	1.62E-05	0.024646
283.99	4.5972	139.07	0.0071906	388.9	421.96	1.779	0.95873	2.6484	204.75	12.552	1.62E-05	0.024741
284.14	4.6138	139.76	0.0071551	388.78	421.8	1.778	0.96014	2.6648	204.63	12.528	1.62E-05	0.024837
284.29	4.6304	140.46	0.0071197	388.66	421.63	1.777	0.96156	2.6815	204.51	12.505	1.62E-05	0.024934
284.43	4.6471	141.16	0.0070844	388.54	421.46	1.776	0.96299	2.6984	204.4	12.481	1.63E-05	0.025032
284.58	4.6638	141.86	0.0070492	388.42	421.29	1.775	0.96443	2.7156	204.28	12.457	1.63E-05	0.025131
284.72	4.6805	142.57	0.0070141	388.29	421.12	1.774	0.96588	2.7331	204.16	12.433	1.63E-05	0.025231
284.87	4.6973	143.28	0.0069792	388.17	420.95	1.7729	0.96733	2.7508	204.04	12.409	1.63E-05	0.025333
285.02	4.7142	144	0.0069443	388.04	420.78	1.7719	0.9688	2.7688	203.92	12.385	1.64E-05	0.025435
285.16	4.7311	144.73	0.0069096	387.91	420.6	1.7709	0.97027	2.7871	203.8	12.36	1.64E-05	0.025539
285.31	4.748	145.45	0.006875	387.78	420.43	1.7699	0.97176	2.8057	203.68	12.336	1.64E-05	0.025644
285.45	4.765	146.19	0.0068405	387.65	420.25	1.7688	0.97326	2.8245	203.56	12.312	1.64E-05	0.02575
285.6	4.782	146.93	0.0068061	387.52	420.07	1.7678	0.97476	2.8437	203.44	12.287	1.65E-05	0.025857
285.75	4.7991	147.67	0.0067718	387.39	419.89	1.7668	0.97628	2.8632	203.32	12.263	1.65E-05	0.025966
285.89	4.8162	148.42	0.0067377	387.25	419.7	1.7657	0.97781	2.883	203.2	12.238	1.65E-05	0.026076
286.04	4.8333	149.17	0.0067036	387.12	419.52	1.7647	0.97934	2.9031	203.07	12.214	1.65E-05	0.026187
286.18	4.8505	149.93	0.0066696	386.98	419.33	1.7636	0.98089	2.9236	202.95	12.189	1.66E-05	0.0263
286.33	4.8678	150.7	0.0066358	386.84	419.14	1.7625	0.98245	2.9444	202.82	12.164	1.66E-05	0.026413
286.48	4.8851	151.47	0.006602	386.7	418.95	1.7615	0.98402	2.9656	202.7	12.139	1.66E-05	0.026529
286.62	4.9025	152.24	0.0065684	386.56	418.76	1.7604	0.98561	2.9871	202.57	12.114	1.67E-05	0.026645
286.77	4.9199	153.03	0.0065348	386.42	418.57	1.7593	0.9872	3.009	202.44	12.089	1.67E-05	0.026764
286.91	4.9373	153.81	0.0065014	386.27	418.37	1.7583	0.98881	3.0313	202.32	12.064	1.67E-05	0.026883
287.06	4.9548	154.61	0.006468	386.13	418.17	1.7572	0.99042	3.054	202.19	12.039	1.67E-05	0.027004
287.2	4.9723	155.41	0.0064348	385.98	417.97	1.7561	0.99206	3.077	202.06	12.014	1.68E-05	0.027127
287.35	4.9899	156.21	0.0064016	385.83	417.77	1.755	0.9937	3.1005	201.93	11.988	1.68E-05	0.027251
287.5	5.0075	157.02	0.0063686	385.68	417.57	1.7539	0.99536	3.1244	201.8	11.963	1.68E-05	0.027377
287.64	5.0252	157.84	0.0063356	385.53	417.37	1.7528	0.99702	3.1488	201.67	11.937	1.68E-05	0.027505
287.79	5.043	158.66	0.0063028	385.37	417.16	1.7517	0.99871	3.1736	201.54	11.911	1.69E-05	0.027634

287.93	5.0607	159.49	0.00627	385.22	416.95	1.7506	1.0004	3.1988	201.4	11.886	1.69E-05	0.027765
288.08	5.0786	160.33	0.0062373	385.06	416.74	1.7495	1.0021	3.2245	201.27	11.86	1.69E-05	0.027897
288.23	5.0964	161.17	0.0062047	384.9	416.52	1.7483	1.0038	3.2508	201.14	11.834	1.70E-05	0.028031
288.37	5.1144	162.02	0.0061722	384.74	416.31	1.7472	1.0056	3.2775	201	11.808	1.70E-05	0.028167
288.52	5.1323	162.87	0.0061398	384.58	416.09	1.7461	1.0073	3.3047	200.87	11.781	1.70E-05	0.028305
288.66	5.1504	163.73	0.0061075	384.42	415.87	1.7449	1.0091	3.3324	200.73	11.755	1.71E-05	0.028445
288.81	5.1684	164.6	0.0060752	384.25	415.65	1.7438	1.0109	3.3607	200.59	11.729	1.71E-05	0.028587
288.96	5.1865	165.48	0.0060431	384.08	415.43	1.7426	1.0127	3.3896	200.46	11.702	1.71E-05	0.028731
289.1	5.2047	166.36	0.006011	383.91	415.2	1.7414	1.0145	3.419	200.32	11.676	1.72E-05	0.028876
289.25	5.2229	167.25	0.005979	383.74	414.97	1.7403	1.0163	3.449	200.18	11.649	1.72E-05	0.029024
289.39	5.2412	168.15	0.0059471	383.57	414.74	1.7391	1.0182	3.4797	200.04	11.622	1.72E-05	0.029174
289.54	5.2595	169.05	0.0059153	383.4	414.51	1.7379	1.02	3.5109	199.9	11.595	1.73E-05	0.029326
289.68	5.2779	169.97	0.0058836	383.22	414.27	1.7367	1.0219	3.5429	199.76	11.568	1.73E-05	0.02948
289.83	5.2963	170.89	0.0058519	383.04	414.03	1.7355	1.0238	3.5754	199.61	11.54	1.73E-05	0.029636
289.98	5.3148	171.81	0.0058203	382.86	413.79	1.7343	1.0257	3.6087	199.47	11.513	1.74E-05	0.029795
290.12	5.3333	172.75	0.0057888	382.68	413.55	1.7331	1.0276	3.6427	199.33	11.485	1.74E-05	0.029956
290.27	5.3518	173.69	0.0057573	382.49	413.31	1.7319	1.0296	3.6775	199.18	11.458	1.74E-05	0.03012
290.41	5.3704	174.64	0.005726	382.31	413.06	1.7307	1.0315	3.713	199.03	11.43	1.75E-05	0.030286
290.56	5.3891	175.6	0.0056947	382.12	412.81	1.7295	1.0335	3.7492	198.89	11.402	1.75E-05	0.030454
290.71	5.4078	176.57	0.0056634	381.93	412.55	1.7282	1.0355	3.7863	198.74	11.374	1.75E-05	0.030625
290.85	5.4266	177.55	0.0056323	381.73	412.3	1.727	1.0376	3.8243	198.59	11.345	1.76E-05	0.030799
291	5.4454	178.53	0.0056012	381.54	412.04	1.7257	1.0396	3.8631	198.44	11.317	1.76E-05	0.030975
291.14	5.4643	179.53	0.0055701	381.34	411.78	1.7245	1.0417	3.9028	198.29	11.288	1.76E-05	0.031154
291.29	5.4832	180.53	0.0055392	381.14	411.51	1.7232	1.0438	3.9435	198.14	11.26	1.77E-05	0.031336
291.44	5.5022	181.54	0.0055083	380.94	411.24	1.7219	1.0459	3.9851	197.98	11.231	1.77E-05	0.031521
291.58	5.5212	182.57	0.0054774	380.73	410.97	1.7206	1.048	4.0277	197.83	11.202	1.77E-05	0.031709
291.73	5.5403	183.6	0.0054467	380.52	410.7	1.7193	1.0502	4.0713	197.67	11.172	1.78E-05	0.0319
291.87	5.5594	184.64	0.0054159	380.31	410.42	1.718	1.0524	4.116	197.52	11.143	1.78E-05	0.032095
292.02	5.5786	185.69	0.0053853	380.1	410.14	1.7167	1.0546	4.1619	197.36	11.113	1.79E-05	0.032292
292.16	5.5978	186.75	0.0053547	379.89	409.86	1.7154	1.0568	4.2088	197.2	11.083	1.79E-05	0.032493
292.31	5.6171	187.83	0.0053241	379.67	409.58	1.7141	1.059	4.257	197.04	11.053	1.79E-05	0.032697
292.46	5.6364	188.91	0.0052936	379.45	409.29	1.7127	1.0613	4.3065	196.88	11.023	1.80E-05	0.032905
292.6	5.6558	190	0.0052631	379.23	408.99	1.7114	1.0636	4.3572	196.71	10.993	1.80E-05	0.033116
292.75	5.6753	191.1	0.0052327	379	408.7	1.71	1.066	4.4092	196.55	10.962	1.81E-05	0.033331
292.89	5.6948	192.22	0.0052024	378.77	408.4	1.7087	1.0683	4.4627	196.39	10.931	1.81E-05	0.03355
293.04	5.7143	193.35	0.0051721	378.54	408.1	1.7073	1.0707	4.5176	196.22	10.9	1.82E-05	0.033773
293.19	5.7339	194.48	0.0051418	378.31	407.79	1.7059	1.0731	4.574	196.05	10.869	1.82E-05	0.034
293.33	5.7536	195.64	0.0051116	378.07	407.48	1.7045	1.0756	4.632	195.88	10.837	1.82E-05	0.034231
293.48	5.7733	196.8	0.0050814	377.83	407.16	1.7031	1.0781	4.6917	195.71	10.806	1.83E-05	0.034466
293.62	5.793	197.97	0.0050512	377.58	406.85	1.7016	1.0806	4.753	195.54	10.774	1.83E-05	0.034706
293.77	5.8129	199.16	0.0050211	377.34	406.52	1.7002	1.0831	4.8161	195.37	10.741	1.84E-05	0.03495

293.92	5.8327	200.36	0.004991	377.09	406.2	1.6988	1.0857	4.8811	195.19	10.709	1.84E-05	0.0352
294.06	5.8527	201.57	0.0049609	376.83	405.87	1.6973	1.0883	4.9481	195.01	10.676	1.85E-05	0.035454
294.21	5.8726	202.8	0.0049309	376.58	405.53	1.6958	1.091	5.0171	194.84	10.643	1.85E-05	0.035713
294.35	5.8927	204.04	0.0049009	376.32	405.2	1.6943	1.0937	5.0882	194.66	10.61	1.86E-05	0.035977
294.5	5.9128	205.3	0.0048709	376.05	404.85	1.6928	1.0964	5.1615	194.47	10.577	1.86E-05	0.036246
294.65	5.9329	206.57	0.004841	375.78	404.5	1.6913	1.0991	5.2371	194.29	10.543	1.87E-05	0.036521
294.79	5.9531	207.85	0.004811	375.51	404.15	1.6898	1.102	5.3152	194.1	10.509	1.87E-05	0.036802
294.94	5.9734	209.16	0.0047811	375.24	403.8	1.6883	1.1048	5.3959	193.92	10.474	1.88E-05	0.037089
295.08	5.9937	210.47	0.0047512	374.96	403.43	1.6867	1.1077	5.4792	193.73	10.44	1.88E-05	0.037382
295.23	6.0141	211.8	0.0047213	374.67	403.07	1.6851	1.1106	5.5654	193.54	10.405	1.89E-05	0.037681
295.37	6.0345	213.15	0.0046914	374.38	402.69	1.6836	1.1136	5.6545	193.34	10.369	1.89E-05	0.037987
295.52	6.055	214.52	0.0046616	374.09	402.32	1.6819	1.1166	5.7468	193.15	10.334	1.90E-05	0.0383
295.67	6.0755	215.9	0.0046317	373.79	401.93	1.6803	1.1197	5.8423	192.95	10.298	1.90E-05	0.03862
295.81	6.0961	217.31	0.0046018	373.49	401.55	1.6787	1.1228	5.9413	192.75	10.261	1.91E-05	0.038948
295.96	6.1168	218.73	0.0045719	373.19	401.15	1.677	1.126	6.0439	192.54	10.224	1.92E-05	0.039283
296.1	6.1375	220.17	0.004542	372.88	400.75	1.6754	1.1293	6.1504	192.34	10.187	1.92E-05	0.039626
296.25	6.1583	221.62	0.0045121	372.56	400.35	1.6737	1.1326	6.261	192.13	10.15	1.93E-05	0.039977
296.4	6.1791	223.1	0.0044822	372.24	399.94	1.672	1.1359	6.3758	191.92	10.112	1.93E-05	0.040337
296.54	6.2	224.6	0.0044523	371.91	399.52	1.6703	1.1393	6.4952	191.71	10.074	1.94E-05	0.040706
296.69	6.221	226.13	0.0044223	371.58	399.09	1.6685	1.1428	6.6195	191.49	10.035	1.95E-05	0.041085
296.83	6.242	227.67	0.0043923	371.25	398.66	1.6668	1.1463	6.7489	191.27	9.9962	1.95E-05	0.041473
296.98	6.263	229.24	0.0043623	370.9	398.22	1.665	1.15	6.8837	191.05	9.9567	1.96E-05	0.041872
297.13	6.2842	230.83	0.0043323	370.55	397.78	1.6632	1.1536	7.0243	190.82	9.9167	1.97E-05	0.042281
297.27	6.3053	232.44	0.0043022	370.2	397.33	1.6613	1.1574	7.1711	190.59	9.8763	1.97E-05	0.042702
297.42	6.3266	234.08	0.0042721	369.84	396.87	1.6595	1.1612	7.3245	190.35	9.8354	1.98E-05	0.043134
297.56	6.3479	235.75	0.0042419	369.47	396.4	1.6576	1.1652	7.485	190.12	9.794	1.99E-05	0.043579
297.71	6.3693	237.44	0.0042116	369.1	395.92	1.6557	1.1692	7.6529	189.88	9.752	1.99E-05	0.044037
297.85	6.3907	239.16	0.0041813	368.72	395.44	1.6538	1.1733	7.8289	189.63	9.7096	2.00E-05	0.044509
298	6.4122	240.91	0.0041509	368.33	394.94	1.6518	1.1775	8.0136	189.38	9.6666	2.01E-05	0.044996
298.15	6.4337	242.69	0.0041205	367.93	394.44	1.6498	1.1817	8.2076	189.12	9.623	2.02E-05	0.045497
298.29	6.4554	244.5	0.0040899	367.53	393.93	1.6478	1.1861	8.4117	188.86	9.5789	2.02E-05	0.046015
298.44	6.477	246.35	0.0040593	367.11	393.41	1.6458	1.1906	8.6265	188.6	9.5341	2.03E-05	0.04655
298.58	6.4988	248.23	0.0040286	366.69	392.88	1.6437	1.1953	8.8531	188.33	9.4887	2.04E-05	0.047102
298.73	6.5206	250.14	0.0039978	366.26	392.33	1.6416	1.2	9.0923	188.05	9.4427	2.05E-05	0.047674
298.88	6.5424	252.09	0.0039668	365.83	391.78	1.6394	1.2049	9.3453	187.77	9.3959	2.06E-05	0.048267
299.02	6.5644	254.08	0.0039357	365.38	391.21	1.6372	1.2099	9.6133	187.48	9.3485	2.07E-05	0.048881
299.17	6.5864	256.11	0.0039045	364.92	390.64	1.635	1.215	9.8976	187.18	9.3003	2.07E-05	0.049518
299.31	6.6084	258.19	0.0038732	364.45	390.05	1.6328	1.2203	10.2	186.87	9.2513	2.08E-05	0.050181
299.46	6.6305	260.31	0.0038416	363.97	389.44	1.6305	1.2258	10.522	186.56	9.2015	2.09E-05	0.05087
299.61	6.6527	262.47	0.0038099	363.48	388.83	1.6281	1.2314	10.865	186.24	9.1508	2.10E-05	0.051587
299.75	6.675	264.69	0.0037781	362.97	388.19	1.6257	1.2372	11.233	185.91	9.0993	2.11E-05	0.052335

299.9	6.6973	266.95	0.003746	362.46	387.55	1.6233	1.2433	11.626	185.57	9.0468	2.12E-05	0.053117
300.04	6.7197	269.28	0.0037136	361.93	386.88	1.6208	1.2495	12.049	185.22	8.9933	2.13E-05	0.053935
300.19	6.7422	271.66	0.0036811	361.38	386.2	1.6183	1.256	12.505	184.86	8.9388	2.14E-05	0.054792
300.33	6.7647	274.1	0.0036483	360.82	385.5	1.6157	1.2627	12.998	184.49	8.8832	2.16E-05	0.055691
300.48	6.7873	276.61	0.0036152	360.25	384.78	1.613	1.2697	13.532	184.1	8.8263	2.17E-05	0.056638
300.63	6.81	279.19	0.0035818	359.65	384.04	1.6103	1.277	14.113	183.71	8.7683	2.18E-05	0.057636
300.77	6.8327	281.85	0.003548	359.04	383.28	1.6075	1.2846	14.747	183.29	8.7089	2.19E-05	0.05869
300.92	6.8555	284.58	0.0035139	358.41	382.5	1.6046	1.2925	15.441	182.86	8.648	2.21E-05	0.059808
301.06	6.8784	287.41	0.0034794	357.76	381.69	1.6016	1.3009	16.206	182.41	8.5856	2.22E-05	0.060995
301.21	6.9013	290.32	0.0034444	357.08	380.85	1.5986	1.3097	17.052	181.94	8.5216	2.23E-05	0.062262
301.36	6.9243	293.34	0.003409	356.38	379.98	1.5954	1.319	17.992	181.44	8.4557	2.25E-05	0.063616
301.5	6.9474	296.47	0.003373	355.65	379.09	1.5922	1.3288	19.043	180.92	8.3879	2.26E-05	0.065071
301.65	6.9706	299.73	0.0033364	354.89	378.15	1.5888	1.3393	20.226	180.37	8.318	2.28E-05	0.06664
301.79	6.9938	303.11	0.0032991	354.1	377.18	1.5854	1.3504	21.568	179.79	8.2457	2.30E-05	0.068341
301.94	7.0172	306.65	0.0032611	353.28	376.16	1.5817	1.3624	23.101	179.17	8.1708	2.31E-05	0.070196
302.09	7.0405	310.34	0.0032222	352.41	375.1	1.578	1.3753	24.87	178.51	8.0931	2.33E-05	0.07223
302.23	7.064	314.23	0.0031824	351.5	373.98	1.574	1.3893	26.932	177.8	8.0121	2.35E-05	0.074478
302.38	7.0876	318.32	0.0031415	350.54	372.81	1.5699	1.4046	29.366	177.03	7.9275	2.37E-05	0.076983
302.52	7.1112	322.65	0.0030993	349.52	371.56	1.5655	1.4214	32.279	176.19	7.8388	2.40E-05	0.079801
302.67	7.1349	327.26	0.0030557	348.44	370.24	1.5609	1.4402	35.825	175.26	7.7455	2.42E-05	0.083009
302.82	7.1587	332.19	0.0030104	347.28	368.83	1.556	1.4613	40.229	174.22	7.6466	2.45E-05	0.086712
302.96	7.1826	337.5	0.0029629	346.02	367.3	1.5508	1.4855	45.836	173.05	7.5414	2.48E-05	0.09106
303.11	7.2066	343.29	0.002913	344.65	365.65	1.5451	1.5136	53.194	171.7	7.4286	2.51E-05	0.096273
303.25	7.2307	349.66	0.0028599	343.15	363.83	1.5388	1.5471	63.239	170.11	7.3065	2.54E-05	0.1027
303.4	7.2548	356.79	0.0028028	341.46	361.8	1.5319	1.5881	77.694	168.19	7.173	2.58E-05	0.11091
303.54	7.2791	364.95	0.0027401	339.54	359.48	1.5241	1.6406	100.09	165.76	7.0247	2.63E-05	0.12195
303.69	7.3034	374.59	0.0026696	337.26	356.76	1.5149	1.7121	138.88	162.51	6.8564	2.69E-05	0.13799
303.84	7.3279	386.66	0.0025862	334.43	353.38	1.5035	1.8202	220.33	157.75	6.6589	2.76E-05	0.16459
303.98	7.3525	403.69	0.0024772	330.47	348.69	1.4879	2.0262	481.1	149.24	6.4105	2.87E-05	0.22343
304.13	7.3773	467.6	0.0021386	316.47	332.25	1.4336	undefined	undefined	undefined	5.8665	3.30E-05	undefined

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APPENDIX I. MATLAB CODE FOR IMPORTING TABLES AND PLOTTING T-S DIAGRAM

```
% run('Import_Data')

%%

plot(EntropylJgKsat, TemperatureKsat, 'b')
hold on
plot(EntropyvJgKsat, TemperatureKsat,'b')

ax = gca;
%ax.YTick = [50, 75, 100, 125, 150, 175, 200, 225, 250,
275, 300];
ax.YLim = [200 800];
ax.XLim = [2.5 3.75];

%plot(EntropyJgK0, TemperatureK0, 'b')

grid on
grid minor
xlabel('Entropy (KJ/Kg*K)')
ylabel('Temperature (K)')
title('R-744 (Carbon Dioxide) Temperature Entropy
Diagram')

plot(EntropyJgK01, TemperatureK01, 'b')
plot(EntropyJgK02, TemperatureK02, 'b')
plot(EntropyJgK05, TemperatureK05, 'b')
plot(EntropyJgK1, TemperatureK1, 'b')

plot(EntropyJgK105, TemperatureK105, 'b')
plot(EntropyJgK2, TemperatureK2, 'b')
plot(EntropyJgK205, TemperatureK205, 'b')
plot(EntropyJgK3, TemperatureK3, 'b')
plot(EntropyJgK305, TemperatureK305, 'b')
plot(EntropyJgK4, TemperatureK4, 'b')
plot(EntropyJgK405, TemperatureK405, 'b')
plot(EntropyJgK5, TemperatureK5, 'b')

plot(EntropyJgK6, TemperatureK6, 'b')
```

```
plot(EntropyJgK7, TemperatureK7, 'b')
plot(EntropyJgK8, TemperatureK8, 'b')
plot(EntropyJgK9, TemperatureK9, 'b')
plot(EntropyJgK10, TemperatureK10, 'b')

plot(EntropyJgK12, TemperatureK12, 'b')
plot(EntropyJgK14, TemperatureK14, 'b')
plot(EntropyJgK16, TemperatureK16, 'b')
plot(EntropyJgK18, TemperatureK18, 'b')
plot(EntropyJgK20, TemperatureK20, 'b')

plot(EntropyJgK22, TemperatureK22, 'b')
plot(EntropyJgK24, TemperatureK24, 'b')
plot(EntropyJgK26, TemperatureK26, 'b')
plot(EntropyJgK28, TemperatureK28, 'b')
plot(EntropyJgK30, TemperatureK30, 'b')

%% Plot Cycles

% % Low Pressure Rankine Cycle
%
% lowRankinetemp1 = [253.65 254.7];
% lowRankineentro1 = [0.83694 0.83694];
% lowRankinetemp2 = [301.9 253.65];
% lowRankineentro2 = [1.9461 1.9461];
% lowRankinetemp3 = [253.65 253.65];
% lowRankineentro3 = [0.83694 1.9461];
% lowRankinetemp4 = [253.65 TemperatureK4(5:11)'
301.9];
% lowRankineentro4 = [0.83694 EntropyJgK4(5:11)'
1.9461];
%
% plot(lowRankineentro1, lowRankinetemp1, 'r',
'LineWidth' ,1.2)
% plot(lowRankineentro2, lowRankinetemp2, 'r',
'LineWidth' ,1.2)
% plot(lowRankineentro3, lowRankinetemp3, 'r',
'LineWidth' ,1.2)
% plot(lowRankineentro4, lowRankinetemp4, 'r',
'LineWidth' ,1.2)

% % High Pressure Rankine Cycle with Recuperation
%
```

```
% highRankinetemp1 = [295.13 304.8];
% highRankineentro1 = [1.2102 1.2102];
% highRankinetemp2 = [750 664.2];
% highRankineentro2 = [2.735 2.735];
% highRankinetemp3 = [TemperatureK6(9:47)' 664.2];
% highRankineentro3 = [EntropyJgK6(9:47)' 2.735];
% highRankinetemp4 = [304.8 TemperatureK12(10:54)'];
% highRankineentro4 = [1.2102 EntropyJgK12(10:54)'];
%
% plot(highRankineentro1, highRankinetemp1, 'r',
'LineWidth' ,1.2)
% plot(highRankineentro2, highRankinetemp2, 'r',
'LineWidth' ,1.2)
% plot(highRankineentro3, highRankinetemp3, 'r',
'LineWidth' ,1.2)
% plot(highRankineentro4, highRankinetemp4, 'r',
'LineWidth' ,1.2)
%
% Brayton Cycle

Braytontemp1 = [300 349];
Braytonentro1 = [2.7446 2.7446];
Braytontemp2 = [750 668];
Braytonentro2 = [3.5286 3.5286];
Braytontemp3 = [349 TemperatureK02(14:54)'];
Braytonentro3 = [2.7446 EntropyJgK02(14:54)'];
Braytontemp4 = [TemperatureK01(9:45)' 668];
Braytonentro4 = [EntropyJgK01(9:45)' 3.5286];

plot(Braytonentro1, Braytontemp1, 'r', 'LineWidth'
,1.2)
plot(Braytonentro2, Braytontemp2, 'r', 'LineWidth'
,1.2)
plot(Braytonentro3, Braytontemp3, 'r', 'LineWidth'
,1.2)
plot(Braytonentro4, Braytontemp4, 'r', 'LineWidth'
,1.2)
```

Text files were imported using MATLAB's import file command. MATLAB then generated a code which was copied and pasted only changing the file names.

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